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THE CHIGNECTO SHIP RAILWAY.

By JOHN F. O'ROURKE, M. Am. Soc. C. E.

The nineteenth century is distinguished for its marvelous advancement in all the arts and sciences connected with communication, or what is the same thing and more, by the development of engineering. At the beginning of the century mail coaches and carrier wagons were the mediums of inland commerce, aided by an occasional river or canal boat; and "old ocean's grey and melancholy waste" was quickened by nothing more speedy than a sailing vessel. The exchange of ideas was slow, traveling between distant points seemed interminable, and the cost of land transportation limited the exchange of ordinary commodities to a small home

market. The gradual extension of canals was a great step forward, as they enabled large bulks to be moved with the small forces then known, reducing the cost of transportation and affording the products of the farm and forest an outlet. But speed is dependent on power, and that great and essential necessity was still wanting. Next steam and electricity came into use, and with them steamships, railroads and telegraphy. Then awoke the spirit of the age, bringing all men in touch and making the world one great market and auditorium. These things developed from small beginnings, like all achievements over nature, and they have yet a long journey to make in the direction of perfection; but the engineer of to-day, with the mighty advances of his predecessors and with the banded sympathy and aid of his greater brothers, is rapidly getting them nearer and nearer to the goal. Many things are in a satisfactory state of advancement, and every day sees something newer and more admirable. The railroad trains of to-day are wonders. So are those marvelous steamers that unite the continents; swift, stately and safe, as obedient to control as the most docile pony, yet often possessing more power than all the horses that would mount an army. The thousand and one other forms in which the genius and progress of engineering show themselves are wonders, and constructive ability has reached the point that it is a common saying, "Anything can be built if you have the money." In such an age, what is more natural than that time-honored methods should be departed from when there are others more fitting. Heretofore artificial works for the transport of vessels have been canals.

There are many situations where commerce requires such transit, and where canals are impracticable because too costly or for scarcity of water.

A ship railway costs less money, needs no water, and can be built almost anywhere.

Many engineers, notably the late Capt. James B. Eads and Mr. E. L. Corthell, M. Am. Soc. C. E., in the United States, and Mr. H. G. C. Ketchum, M. Inst. C. E., in Canada, have advocated ship railways as substitutes for canals. Messrs. Eads and Corthell, finding capitalists shy of investing in what, to them, was visionary, applied to Congress for aid without success. Mr. Ketchum's appeal to the Dominion Parliament was because of a similar reason, and resulted in a subsidy sufficient to insure the construction of a ship railway across the

Isthmus of Chignecto, between the Bay of Fundy and the Gulf of St. Lawrence.

This will be the first application of rails to navigation, and Canada has secured the honor by guaranteeing for twenty years an annual sum equal to one two-thousandth the yearly receipts of the New York Custom House. As when built it will, most likely, be self-supporting, Canada may be said to have purchased the honor with a little accommodation.

If ship railways will do all that is claimed for them, and it is morally certain that they will, a new era is about to open in transportation. A ship is not a fish, though that seems almost asserted in the stress that is laid on the popular statement that water is its natural element; and usage makes it difficult to think of a ship apart from water. It is lost sight of that a ship is a land-built structure of the strongest and stiffest design, fitted to withstand the tossing and buffeting of the highest seas and the wildest storms. Now pounded and overswept by a colliding wave, and the next moment bare of water almost to the keel, while all the time, perhaps, the rocking and plunging and the mighty wind is tearing the rigging and snapping the spars. Nevertheless, vessels that have lived through fifty years of such life are not uncommon.

Light-houses and breakwaters tell enough of the fury of the sea to ridicule any pretense of hydrostatic pressures around ships excepting in still water; or that naval constructors build ships dependent on the water pressure to keep the cargo from bursting out the sides; or that water is the natural element of ships in the caressing sense used by the good people who object to ship-railways as snares of destruction.

It therefore follows that a ship resting on blocks at short intervals along the keel and bilges, is adequately supported; and that if borne on a suitable carriage over a smooth and rigid roadway, it will make the journey with as much ease as under the most favorable conditions afloat, or, generally speaking, that a ship is as well adapted to traveling by rail as by water.

The Chignecto Ship Railway will soon be an accomplished fact. Others will quickly follow, and it takes no gift of prophecy to forsee the time when every isthmus will pass ships dry shod, if need be, and when inland cities will be open to navigation with rails, and the freight-car and the ship will occupy adjoining sidings at the warehouse and factory. It is not beyond belief that a twentieth-century siege may be conducted by war vessels on temporary roads, opposed by traveling fortresses on strategic railways that defend every approach.

Fig. 1 is a map of Nova Scotia, showing the relation of the ship railway to the coasting trade; also the saving of distance that the new

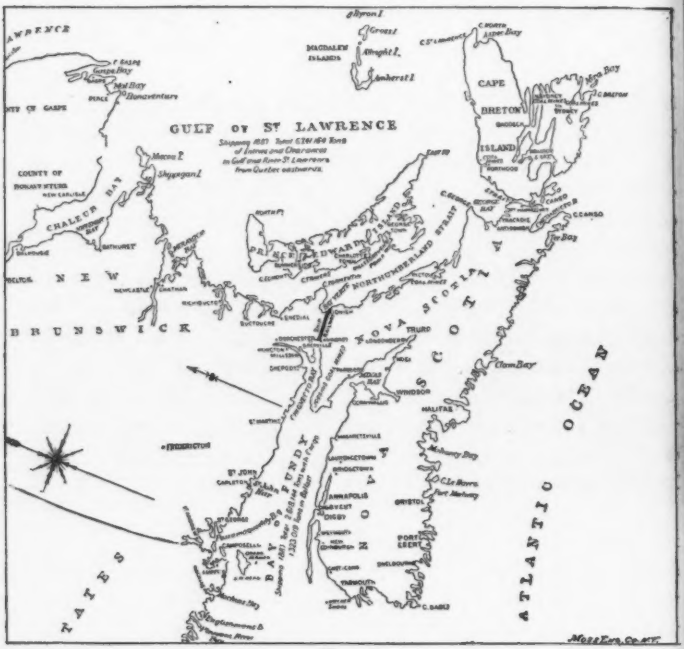

FIG. 1.

inside route will effect for vessels that are now obliged to navigate around the circuitous and dangerous coast.

FIG. 2.

Fig. 2 is a topographical map of the Isthmus of Chignecto, and shows the location of various canal and ship railway lines proposed at different times, and the present line that is now under construction.

The ship railway will be 17 miles long, and will be on a straight line from end to end, running through a country moderately rolling, with only one watercourse to cross, and generally favorable to the rectilinear location, and the two-tenths per cent. maximum grade adopted.

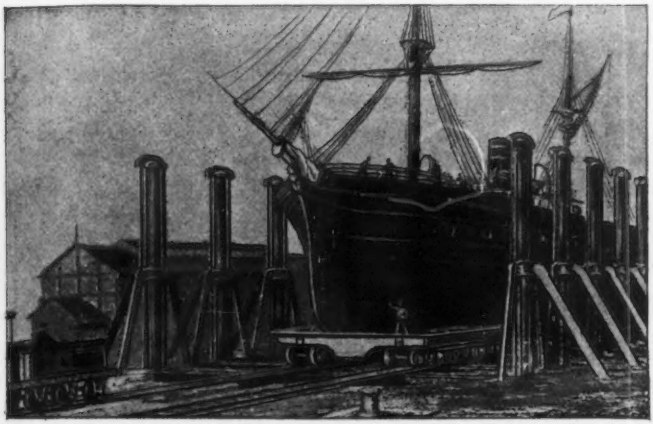

FIG. 3.

Fig. 3 shows a vessel as it will look in the lifting dock, ready for transportation. The vessel is seen resting on blocks along its keel and bilges, supported on platform cars nearly 40 feet in width and carried by two hundred and forty wheels arranged in four lines to run on two tracks of standard gauge, 18 feet between centers. The gridiron on which the ship and cradle (as the cars are called) move up and down in the lifting dock, is like the deck of a bridge, with the floor beams arranged in pairs, slightly separated to admit the hydraulic presses between them, and connected by track stringers under the rails, as is common in bridge work. The hydraulic presses are twenty in number, and are designed to lift a vessel carrying 1 000 tons of cargo, together with the cradle and gridiron. They are arranged in two lines, 21 feet longitudinally and 64 feet transversely between centers, and have a maximum stroke of 40 feet. The cross-heads on the inner cylinders are attached to the floor-beams with eye-bars a little longer than the stroke of the presses.

When a vessel is to be lifted, the gridiron, with a cradle on its tracks,

is lowered, and the vessel is hauled into position with hydraulic capstans. Water is then forced into the presses until the keel blocks are brought to a bearing, next the bilge blocks are drawn into place and the pumps are again started, raising the gridiron in less than ten minutes to a position where its tracks are slightly above those of the railway. A connected system of heavy iron chocks, supported by the masonry, is then shot under the ends of the girders by hydraulic power, the gridiron is lowered to a bearing on them, and its tracks are connected with those of the railway, of which it is now a part. Two locomotives will haul the ship across the isthmus in less than two hours, and a reverse operation to that described speedily restores the ship to the water.

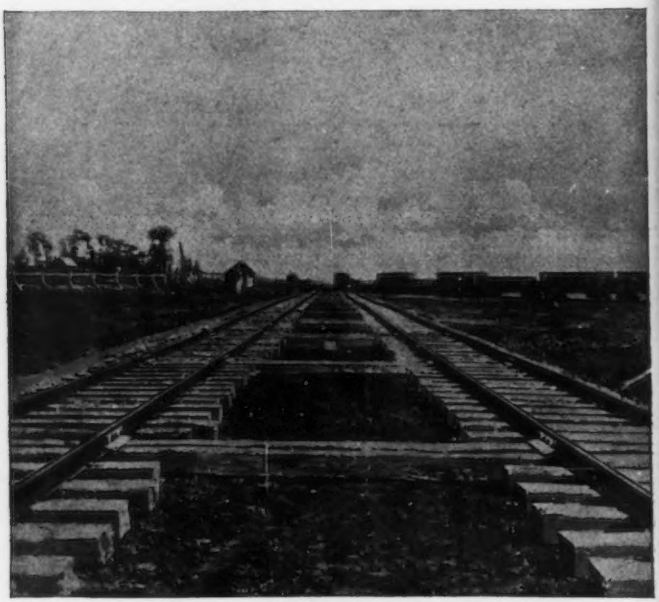

FIG. 4.

Fig. 4 shows the railway track. It is composed of 110 pound rails laid on 9 feet x 12 inch x 7 inch ties; the two ties at the joints being 27 feet long and of the same section, connecting both tracks and preserving the gauge of the inner rails. The road will be stone-ballasted throughout, and will be tested with rolling loads of a greater weight than the

maximum size ships, to insure freedom from subsequent settlement, and smoothness and rigidity when operations begin.

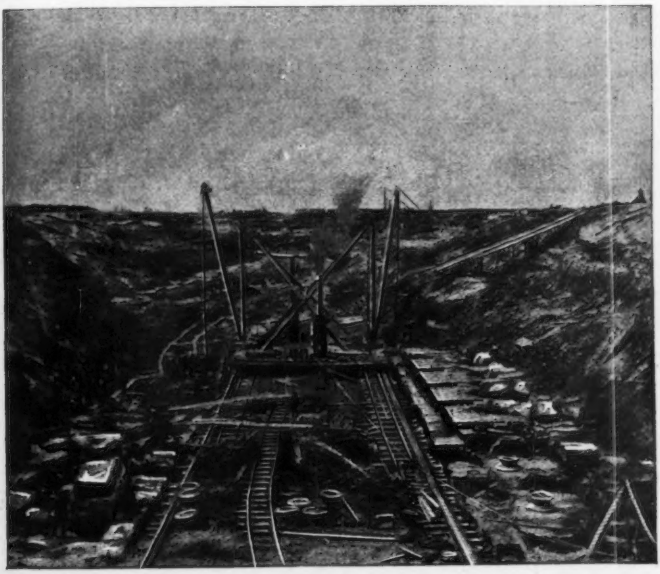

FIG. 5.

Fig. 5 shows work in progress at the Amherst end, that at Tidnish being in a similar state of advancement. The heavy cutting at Tidnish is 1½ miles long, and contains over 500 000 cubic yards; composed of hard pan, boulders and rock, of which less than 10 per cent. remains to be excavated. There is a 30 feet stone arch over the Tidnish River, which is finished. The track is laid for 13 miles from the Amherst Basin and ballasting has been progressing for several months.

The termini differ greatly, because of the immense tides in the Bay of Fundy. At the Tidnish terminus, where the tides are but 7 feet, a lifting dock with moles attached and a dredged basin and channel, comprise the main works. The Amherst terminus is situated at the mouth of the La Planche River, where there is a variation of over 50 feet between extreme high and low tides. Anchorage at low water is impracticable near the shore, so a tidal basin is excavated inshore and connected with the

harbor by a channel. The basin is 500 feet long, over 300 feet wide, and 50 feet deep, the bottom being about at the level of low water. The entrance gate and sea walls are of heavy masonry, the top being at the common level of the top of the lifting dock and the railway. The top of the gate proper is 17 feet lower, or 12 feet below high water spring tide, and retains a minimum depth of 32 feet in the basin. The lifting dock is at the inner end of the basin and is 270 feet long. Vessels will be able to enter or leave the basin during the higher stages of the tide, while the excellent anchorage off shore and the large storage capacity of the basin, insure a continuity of traffic uninterrupted by the extraordinary fluctuations of the bay. Sir John Fowler and Sir Benjamin Baker are associated with Mr. Ketchum as the engineers. Messrs. John G. Meiggs & Son are the contractors for the entire work. The contract for the graduation, masonry, track, terminal and harbor work, etc., being re-let by them to Messrs. Dawson, Symmes & Ussher; and that for the hydraulic plants of the lifting docks to Messrs. Easton & Anderson. (A more extended paper on this important work is promised by Mr. O'Rourke, on its completion.)

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SELF-PURIFICATION OF FLOWING WATER AND THE INFLUENCE OF POLLUTED WATER IN THE CAUSATION OF DISEASE.*

(A BIOLOGICAL STUDY.)

By CHARLES G. CURRIER, M.D., Mem. N. Y. Acad. of Med.

WITH DISCUSSION.

Our water sheds being in great part composed of diluvial and alluvial formation can, besides holding much in the depression of their uneven surfaces, take up and retain a varying amount of the water precipitated from the clouds, or coming directly from condensation of atmospheric vapor or otherwise reaching the earth. It may be considered that dry, sandy soil takes up 45 per cent. of its volume of water;† while dried turf can absorb perhaps ten times its weight of water by reason of the great surface created by the enormous number of minute particles. The finely divided elements of the soil can furthermore, by their capillarity, cause water to rise through their substance to a considerable

* Read before the American Society of Civil Engineers, November 5th, 1890.

The first pages are introductory, and added chiefly as a succinct reply to questions propounded by members of the Society at the time of the reading of the paper. For brief explanation of the bacteriology involved, see Appendix (page 42).

† Meister : Soyka, *Der Boden*, page 83.

height, which in loam is many times greater (though the rise is there much slower) than in the coarsest earth (gravel). The hydrostatic power of earth is much augmented by the presence in it of organic matter,* and the cleaner the ground is kept the drier it is.

More or less deep in permeable earth, underlain with impermeable strata, water is regularly found completely filling all the pores, and this is called the "ground-water." Not to explain at length the zonal differences of the layer of earth between the surface of the ground and the surface of the ground-water, it may be said briefly that water passes rapidly through this when of coarse gravel, while in very fine soils many months may in our region be required for a given water to make its way from the air down to the surface of the ground-water. By taking up certain constituents and losing others it may have considerably changed its character in the downward passage. Most varieties of the micro-organisms which swarm on and near the surface of the ground are less able to find the conditions favorable to their life and activity after descending a few feet. Some porous soils seem to be permeable to bacteria for less than 6 feet. Hence the ground-water is often quite free from bacteria. The best deep springs show few or none of these, and the uncontaminated water flowing directly thence is, unless highly impregnated with minerals, the most wholesome of beverages.

These underground bodies of water may be regarded as subterranean lakes or water-courses, usually flowing several feet daily toward the streams or lakes draining the basins in which they are, and the level of the ground-water is lowest near such draining streams or bodies of water. Hess† found that in northern Germany such water moved sometimes more than 100 feet per day. Thiem‡ judged from observations on the Bavarian plateau that from 9 to 25 feet was an accurate estimate of the daily advance of the ground-water there measured. It is largely owing to such enormous and well-protected reserves that the lakes and streams of our region maintain the average level to which they tend to return when temporarily lowered by drought or when swollen by freshets.

For about thirty-five years, since first v. Buhl and Seidel called attention to the principle, v. Pettenkofer and others have insisted upon what they consider the causal relations existing between the moisture changes indicated by the varying height of the ground-water

* Hoffmann : *Archiv für Hygiene*, II, 145.

† *Zeitschrift des Architekten und Ingenieur Vereins* in Hannover, XVI.

‡ *Journal für Gasbeleuchtung und Wasserversorgung.* 1880.

level and the prevalence of epidemics which, they claim, are not much if at all, influenced by purity of drinking water as such, by mere filth or any other than this particular element which induces the manifestations of activity on the part of the causative germ. Soyka's experiments* led him to consider that in a long, dry spell of weather, such as precedes the lowering of the ground-water level, there is a more or less uninterrupted capillary flow towards the surface. With this, living micro-organisms that may be in the ground are carried upward into the outer layers of the soil. From the evaporation of this water the microbes remain on the surface or somewhat deeper. With rain they may be washed along or return into the ground. If dry weather persist, they may be stirred up with the dust and in their exsiccated form carried far through the air, as has been rendered evident by several examinations where they have been found many miles out above the open ocean. After the evaporation of water coming up to the surface, the previously-dissolved substances remain in the upper layers of the ground, and the water there becomes a more concentrated solution of these substances. The ground-water is in itself quite harmless. Its significance is as an indicator of the fluctuation in the moisture of the ground, and the cleaner the earth is kept the less importance is attached to hydrometric changes.† While it is not denied that germs may have to be present to cause the disease, this doctrine claims that they can produce disease only when the local conditions favor their activity.‡

Repeated and careful observations have made those of the Munich school who contend for this "localistic" theory insist that, excepting, of course, where by artificial drainage we intentionally cause water to be drawn away from the ground, such a disease as, for instance, typhoid fever, increases as the ground-water sinks, and no considerable epidemic of typhoid occurs without at the same time a sinking of the ground-water level. No considerable typhoid epidemic occurs in the period of a large rise of the ground-water, say the champions of the interpretations which v. Pettenkofer has given to the facts as observed at Munich.‖ This view is, however, not in consonance with the facts of all epidemics.

The majority of practical hygienists do not indorse these views in their fullness. The definite advances made of late years by biological

* Prager med. *Wochenschrift*, 1885.

† Dr. Max v. Pettenkofer: Deutsche med. *Wochenschrift*, Nov. 28, 1889, page 977.

‡ Dr. Max v. Pettenkofer: *Archiv für Hygiene*, iv, 249; v, 353.

‖ Prof. J. Soyka: *Archiv für Hygiene*, vi, 257.

study have given further and further ground for believing that, among other diseases, such ones as typhoid and probably cholera are solely caused by the vital activity (within the human organism) of the specific bacteria of these diseases. Inasmuch as a great number of sporadic and epidemic attacks of these scourges have been clearly traced to the consumption of water containing the infective elements of these diseases, and no other factor has there been constant or frequent, this belief is called the "drinking-water theory." While emphasizing the baneful effect of polluted drinking-water, it is of course admitted that unclean ingesta or anything that introduces these living bacteria into the alimentary canal, may be the means of carrying the infection into the system.

In the case of cholera the localistic theory seems more difficult to refute than in the case of typhoid. Yet in India, as elsewhere at the time of each epidemic, much circumstantial evidence has accumulated to make us suspect that the presence of the infective element in the alimentary canal is the prime factor in inducing the disease. Bacteriology has strengthened this opinion from the time when Koch* found the peculiar spirillum in cholera dejecta and in the intestines of those who had died from cholera. The presence of this characteristic microorganism in the water of a certain tank was demonstrated by him, together with the fact that in the neighborhood in question, only those who had drunk of this water had the disease. The facts were presented with Koch's unsurpassed precision, and carried more conviction than any single one of the various similar histories. Still no theory suffices to explain the exemption of certain cities (as Stuttgart, Salsburg, Innsbruck, Hanover, Versailles, Rouen, Lyons, and others) from any outbreak during the various epidemics. These important centers of travel and commercial intercourse did not succeed in barring all entrance of infection, and their supplies of potable water were not conspicuously superior.

On page 211 of Koch's report (1887), an impressive diagram is given to show the permanently decreased cholera mortality in Calcutta since November 1st, 1869, from which time the city has been supplied with hydrant-water which, on analysis, seems very good. The tank water formerly used in the city (as even now in the suburbs) was—like nearly

* Bericht über die Thätigkeit der zur Erforschung der Cholera im Jahre, 1883, Entsandten Commission, page 182. Berlin, 1887.

everything in India*—exceedingly filthy. The water of the polluted Hoogly River, likewise more used formerly than at present, contained 250 000 bacteria per c.c. when examined by Koch.

Among those who consider that intelligent admission of ignorance is preferable to subserviency to a theory, it is proper here (because of his great and favorable opportunities for many years of observing cholera in its endemic haunts) to mention the statements of Surgeon-General Cunningham.† He observed that some districts in India are wholly immune at all times, regardless of the contaminated state of the water supplies. In his experience, disinfection of cholera dejecta is useless, and drinking-water does not cause cholera. Unlike some who have never been near India, or have not remained there for many weeks, he considers that railways have not in any way influenced the spread of epidemics of cholera in India either in time, place, or extent. It is needless to say that others dispute the accuracy of these inferences, and there is a great amount of evidence on both sides.

Selecting then the best portions from these conflicting theories, we find that both condemn a drinking-water having many‡ and various bacteria, and both call for abundant supplies of good water for individual and public uses. At the last International Congress, in Vienna, in 1887, where the leading hygienists of the world were gathered—and among them the high priests and acolytes of the ground-water theory—there was an unanimous and unmistakable expression of the opinion that, in order to the maintenance of a high degree of health, cities need an abundant supply of the purest water attainable by them.

The green algæ and the diatomaceæ are found only in waters well supplied with light and air, with no excess of organic matters, and free from regular sources of infection. But the written and oral expression of the opinions of others familiar with the subject, as well as an extensive personal observation, leads me to believe that a water containing a large number of bacteria, especially if many varieties are detectable in it, is objectionable as a beverage so long as it has not undergone the sterilizing influence of heat, or of other adequate means of purification. No sufficiently prolonged and repeated clinical observations by medically-qualified workers have yet accumulated, to determine just what harm, if any, the ordinary earth (and water) bacteria can produce when extensively consumed by human beings. Most of these micro-organisms are classed as harmless.

* J. B. Hamilton, M.D., *British Med. Journal*, October 4th, 1890, p. 787. (Enteric fever in India.)

† Cholera. What can the State do to prevent it? By J. M. Cunningham, M.D., etc. Calcutta, 1884.

‡ Even in Emmerich und Trillich's Book, München, 1889, page 168, we find this admitted.

Unlike pathologists in some other countries, we do not here so often detect the ova of tænia and other intestinal parasites as having come from the ordinary water supply;* and although we here, of course, recognize that some nematodes develop first in water, and are thence carried to man, we are not confronted with such unpleasant statistics as Sievers derived from his obductions in Kiel.†

From the time when Dr. Michel‡ first called attention to the influence of contaminated water in causing typhoid fever (1855), and Snow in 1848, said that cholera was due to the use of infected water, an enormous mass of evidence has been constantly accumulating and has caused nearly all physicians among us to believe that such influence has usually been operative in those cases that they have met, even if for various reasons the exact source of the infection could not be traced. Furthermore, numerous attacks of diarrhœal disorders have been explainable in no other way.

Endorsing Naegele, the botanist, and other partisans of the extreme ground-water theory, Emmerich‖ performed a series of experiments upon animals, and from these inferred that decomposing organic matter taken with water into the stomach could not cause harmful symptoms. As evidence of his sincerity he daily, for two weeks, drank from one to two pints of very foul water taken from a hospital brook, which to the naked eye and to chemical tests was distinctly infected with sewage and which showed a large amount of chlorides, ammonia, and various organic substances. During the first three days he noticed slight gastritis, yet during the remainder of the fortnight no ill-effects were recognized. A month later, having acquired a gastro-enteritis, he again tested upon himself in the same way the effect of the same sort of water but observed no detriment to his health. Very few could be induced to repeat such unpleasant subjective experiments, and many such would only prove that polluted waters vary in character and are not at all times, and under all circumstances, demonstrably harmful. Most persons would, if solely for æsthetic reasons, strongly object to drinking freshly-polluted waters.

Prof. Chandler calls my attention to the immunity of Albany, N. Y. (during the last two decades), from any serious outbreak of disease attributable to bad drinking-water, although the Hudson River, supplying water for its hydrants, is at times contaminated with the city's own sewage and certainly with that of the neighboring city of Troy. I have never investigated the water supplied to Albany, but am not surprised to hear (from those who have inquired) that the citizens regard the water with suspicion and suspect it of causing diarrhœal and other disorders.¶ It would seem as though cholera germs getting into such a water would greatly augment the danger of a cholera epidemic.

The experiments of Prof. J. v. Fodor§ show that unless steril-

* Knoch: *Virchow's Archiv*, xxiv, 453.
Blanchard: *Revue d'Hygiène et de police sanitaire*, le 20 Sept. & le 20 Oct., 1890.
† Sievers: Schmarotzerstatistik, Kiel, 1887.
‡ See *Annales d'Hygiène Publique*, etc., Dec., 1889, page 541.
‖ *Zeitschrift für Biologie*, xiv, 563.
¶ See New York City papers of Jan. 25, 1891, for mention of typhoid epidemic at Albany caused by drinking river water.
§ *Archiv für Hygiene*, iii, 118.

ized, as by boiling, foul waters may be assumed to be dangerous, even if not obviously so; for they tend to cause some degree of putrid infection which, however vague, may, like extreme hunger* and other "cachexies" act to weaken the system and render it less resistant to infection. Besides abundant laboratory evidence of this sort, the most impressive of tests have unintentionally, but in general with apparently very serious results, been made by so many bodies of men and communities that the mere enumeration would cover many pages. When more than one-tenth part of a population is attacked by typhoid after drinking of the water from a presumably pure mountain stream, stored for consumption, but into which a small amount of typhoid dejecta had been introduced (to cite the familiar experience of Plymouth five years ago); the fact that the majority of those using the same water, perhaps uncooked, revealed no symptoms of the malady, does not invalidate our right to interpret these epidemics by the light of our present knowledge and so infer that a polluted drinking water may be very dangerous. If Vienna, paralleling London's well-known experiences with cholera and typhoid, averaged many times the number of deaths from typhoid when she supplied her people with the water of the swift, "blonde" Danube, that she has had since the hill-spring supply has been furnished, the fact is very significant. But here, too, v. Pettenkofer has come forward with his keen interpretation of the facts and has tried to show that infected water had nothing to do with the causation of the disease.

There are a few authentic laboratory experiments† which go to show that, in ordinary water, disease-producing bacteria are, at least in some cases, more or less speedily destroyed by the hardier saprophytic varieties that abound in all supplies of doubtful quality. But since first Moers‡ found the bacillus of typhoid in water suspected of having caused the disease (the finding receiving Prof. Gaertner's confirmation when it was later questioned) and Michael‖ likewise detected these (under corresponding circumstances and was endorsed by Prof. Johne),

* Canalis und B. Morpurgo, Fortschritte der Medicin, Sept. 15 and Oct. 1, 1890.

† Arnould: *Revue d'Hygiène*, ix, 27. Freudenreich: Annales de l'Institut Pasteur, iii, 200. De Giaxa: *Zeitschrift für Hygiene*, vi, 102; Annales de Micrographie, 1890. Garré: *Correspondenzblatt der Schweizer Aerzte*, 1887. Karlinski: *Archiv für Hygiene*, 1889, 113-432; also 1890, page 464. Kraus; *Archiv für Hygiene*, 1887, 205. Zagari: Giornale internazionale delle scienze mediche, ix.

‡ Ergänzungshefte zum *Centralblatt* für allgem. Gesundheitspflege, ii, 2, 144 (in 1886).

‖ Fortschritte der Medicin, iv, ii, 353 (in 1886).

For list of some others who have detected the genuine typhoid germ in suspected water, see Uffelmann's Jahresbericht, 1890, page 224.

a considerable number of competent bacteriologists have in different countries reported similar results. Others have verified these facts by adequate laboratory trials. So we are to-day allowed to believe that the micro-organisms which cause some diseases can, despite the antagonistic influence of ordinary bacteria and influenced by various conditions which we as yet do not clearly understand, live at times for at least several days in natural and artificial waters of varying degrees of purity and still retain enough of their specific vitality to induce more or less serious cases of disease. The terrestrial conditions influencing the activity of these presumable causes have not yet been established with sufficient accuracy.

Chemistry affords us no sufficient test of the freedom of a water from the infective principles which cause serious diseases or which lessen the sum total of the vital forces and increase the susceptibility to infection. Yet, in lack of sufficient biological study of the question of self-purification of polluted sources of water-supply, the extensive and valuable reports of chemical examinations of numerous streams are very interesting and instructive.

Quite contradictory in their conclusions to almost all others, the eminent investigators engaged on the work done by the famous English Commission, in the years following 1868, asserted that no river, even in a course of more than 100 miles, became purified after pollution by organic matter. In all other countries the opinions are, and generally have been, that after flowing a number of miles from the place where sewage has entered, the river has chemically purified itself of at least a portion of the organic matters introduced. Thus the chemists connected with the investigation of the Seine waters found* that this river, after becoming very foul from receiving the sewage of Paris, purified itself in a flow of from 109 to 150 kilometers, so as to have returned to the same chemical quality that it had before reaching Paris. Of the numerous German presentations of similar facts that of Hulwa† is, like the repeated examination of the Isar at and below Munich, still more convincing. Hulwa found that the Oder, after receiving the sewage of Breslau, had completely purified itself chemically in a flow of 32 kilometers (or less than 20 miles). In this country the determinations of the late Prof. Wm. R. Nichols‡ made him conclude that various rivers of Massachusetts

* *Vierteljahrschrift für öff. Gesundheitspflege*, ix, 434. Durand-Claye: Assainissement de la Seine, Paris, 1885.

† Ergänzungshefte zum *Centralblatt* für allg. Gesundheitspflege, i, 68.

‡ Mass. State Board of Health Report, 1875.

went through a similar process. Very interesting in this regard are Long's* results, as he tested the changes in dilute sewage flowing from Chicago for miles down a canal. The element of considerable constant or irregular dilution is thus omitted till the Illinois River is reached. The oxidizing process causes the water to become much purer at Ottawa, after 80 miles of flow, and it is still purer at Peoria, 150 miles from Chicago. The most notable improvement Long found to be with respect to free ammonia, and the process was decidedly more active in summer than in winter.

Stagnant water and that standing in vessels, require much longer time than moving water to have a definite degree of oxidation take place in the organic substances present. Most chemists have been led to attribute a very great influence in this respect to the numerous bacteria which are found to be present in all sewage-contaminated waters. That the "nitrifying" varieties of these accomplish the work of oxygenation was first declared by A. Müller.† Emich‡ supported this theory by experiments in which he found that water purified itself chemically if many bacteria were present; but the same water sterilized by heating and kept germ-free did not improve chemically until, from exposure to the air, other bacteria had entered. Direct oxidization by the oxygen of the air did not take place, and the action of ozone and peroxide of hydrogen was less potent than that induced by bacterial activity. Heræus‖ studied the question and found that bacteria differed greatly in their activity in this direction. He got no oxidation with any of the few river and earth varieties that he tested. In England and in Massachusetts recent experiments furnish additional corroboration of this theory of the important function of nitrifying bacteria.§

Biological investigations into the self-purification of rivers have been very scanty and incomplete. Frank,¶ Prausnitz,** and Uffelmann,†† examining, respectively, the Spree, the Isar, and the Nebel, found that the number of bacteria present before the accession of the city sewage had increased with the addition of this polluting fluid. Within a dozen

* *American Chemical Journal*, x, 26. London *Chemical News*, June 29, 1888.

† König, Berlin, 1887, page 99.

‡ *Monatshefte für Chemie*, vi, 77–94. *Chemisches Centralblatt*, 1885, 333.

‖ *Zeitschrift für Hygiene*, i, 193 and 213.

§ P. F. Frankland: *Journal of the Chemical Society*, 1888, No. 53, page 373. Massachusetts State Board of Health Report for 1888, supplement.

¶ *Zeitschrift für Hygiene*, iii, 355. ** München, 1890. †† *Vierteljahrschrift für öff. Gesundheitspflege*, xxii, 377.

miles or so of the place of the introduction of sewage, the water, even if biologically inferior, seemed usually not much worse than might have been the case if no city filth had contaminated the river. Schlatter* has recently reported that the Limmat usually purified itself bacteriologically to a marked degree within 9 miles after receiving the sewage of Zürich.

These and similarly executed observations are very important, even though the present methods of examination have not reached the degree of perfection (aimed at by Chantemesse, Holz, and others) that shall enable us to cultivate the morbific germs, present in a given example, by means of some ideal medium that at the same time suppresses any or all others, as we may elect. The commoner bacteria are, in general, hardier than the noxious ones and (as in the laboratory, so in nature) tend as a rule, to destroy these harmful ones, or at any rate, prevent their increase. Both kinds are exceedingly alike in many respects, and certain varieties of the harmless ones are very difficult for an expert to differentiate from well-known disease-producing varieties. Considering, therefore, the present status of practical bacteriology and its limitations, it seems a very fair test of the question whether rivers purify themselves from infection introduced, if we compare the numbers of germs found pre ent in the water taken at different points. We can then reason from the figures and facts thus afforded. Hence, I herewith present data from some of the analyses which I have at various times been able to make. All have been done according to Koch's gelatine method, and—what is most important—all the waters have (unless the contrary is mentioned) each been "plated" within a few minutes after taking the samples, in sterilized bottles and with the utmost care, from the body of water. To keep the nutrient gelatine from melting when the prepared plates are exposed to warmth, I use a portable "cool chest," which allows the method to be successfully employed in summer, even amid the high heat of the "Great American Desert."

A swift, foaming mountain brook, that of the Kaaterskill "Clove," was tested at a part where it might have recently received the drainage of several hundred people, and where dilution seemed less conspicuously an obstacle to accuracy than would be expected in many parts of the brook's course. The ground was wet with rain which had fallen within twenty-four hours. Hence, the element of dilution and possibly

* *Zeitschrift für Hygiene*, ix, 1, 56.

the entrance of new (surface) bacteria make the figures lack absolute value.

September 11th, 1890:	Bacteria in 1 c.c.
Brook in Catskills (after chance of pollution).....	54
Same brook 1½ miles further on (after 300 feet of irregular fall).....	49

Situated amid the most rugged and densely-wooded of mountains, Cœur d'Alène Lake supplies the Spokane River, which is tributary to the Columbia River. Pend d'Oreille Lake is in similar wild country, and its effluent stream enters the Columbia River in British America. The former lake was not tested, owing to the greater difficulty and delay involved in getting out from it—an element which could imperil the accuracy of the results. It probably has fewer bacteria than the lake given, which therefore answers here the purpose. The water was plated within five minutes of obtaining the sample 50 feet out in the lake, at a time shortly after a rainfall and in a portion near a small lumber camp.

June 10th, 1890 (clear):	Bacteria in 1 c.c.
River flowing into Pend d'Oreille Lake (rain on previous day).....	154
Pend d'Oreille Lake, highest number found*.....	43
Spokane River, 4 miles above Spokane Falls.....	69
" " just below city and falls (Spokane)...	129
" " 1 mile further down.....	125
Willamette River, 4 miles above Portland, Oregon....	44
Columbia River, 37 miles below Portland and 31 miles below confluence with Willamette.....	52

The Mississippi affords in places excellent chances to study the question. The changes undergone by the decomposable elements of the vast quantities of logs and wood-refuse that the lumber industries cause to be present here, do not seem to cause nearly so great an increase in the number of bacteria present, as though the organic matter were wholly in the form of that coming from the surface drainage of agricultural districts and many habitations. This I have observed in the Ottawa River of Canada and in other parts of the North.

* This number was above that of the average of Western Lakes. Thus, Union Lake, upon which Seattle verges, averaged in the middle of its surface (June, 1890) only 13 germs per c.c. out of three analyses which I made of its waters.

Above the St. Anthony Falls the Mississippi has already drained a fairly populous portion of its valley. After passing over the falls the water receives sewage, then falls rapidly for a short distance, and in the next 10 miles does not appear to receive much other contamination. The time when the water was taken seemed very favorable for excluding any unusual degree of this, yet in view of the figures I am inclined to suspect some contamination not detected. The fact that the sample from St. Paul stood unplated for an hour may explain the number found. Even a passenger boat crossing up-stream may at times cause a decided increase in the number of bacteria in some parts of the current. This I know to my cost, from having thereby had a series of plates made at Sault Ste. Marie rendered unreliable for the purposes of this paper.

June 8th, 1890 (clear and sunny):	Bacteria in 1 c.c.
Mississippi River, above Minneapolis	620
" " just below Minneapolis	794
" " above St. Paul, 10 miles below former sample; no obvious source of pollution	843

(Last sample kept one hour before plating.)

But for its short flow, the Passaic River furnishes every feature that could be desired for the study of this question. The northernmost tributaries furnish pure water in most parts. Between the junction with the Pequannock and the Great Falls at Paterson (6 or 7 miles) its way is through a rocky valley receiving relatively little drainage. In that distance, and with the Great Falls, the descent is 100 feet. Before the partial obliteration of the Little Falls, recently accomplished for economic agricultural reasons, I endeavored there to determine the influence of the violent agitation upon the number of micro-organisms in the stream before and after such action:

February 13th, 1889 (sunny and cold):	Bacteria in 1 c.c.
Lake Macopin, highest number found	57
Pequannock River (below a hamlet)	361
Passaic River, above Great Falls at Paterson (after draining 855 square miles)	573
Passaic River, below Great Falls in Paterson (near a mill)	1030 ±
Passaic River, below railway bridge (after receiving sewage)	2172
Water from Newark hydrant (supplied from lower Passaic River)	4000 ±

November 5th, 1889 (cloudy and cool):	Bacteria in 1 c.c.
Passaic River, ½ mile above Little Falls	372
" " 10 feet from rocky bank, just above falls	720
" " " " " " " " below "	704
" " Middle of Lincoln's bridge (5 miles down stream)	631
" " just above Great Falls	600 ±
" " just below " "	600 ±
" " Middle of railway bridge (after mingling of sewage)	1934
" " " " " " above Passaic	1907

[± Denotes partial liquefaction of plates such as to prevent absolutely precise determination.]

After leaving the region of Port Jervis the Delaware gradually enlarges, but regularly receives comparatively little objectionable drainage till Easton is reached at the junction of the Lehigh. Here it has mingled with it the more or less recent and diluted refuse of probably more than one hundred thousand people. All the way down to Trenton, over 50 miles further, the drainage is considerable and comes from a large area having many farms and numerous inhabitants. Thirty miles beyond Trenton, Philadelphia takes part of its water from this river after it has flowed from a water-shed supporting over half a million people.* My examination was made at a time when considerable rain had fallen in this valley during the previous three days, and the biological results must be numerically regarded as those of the river when at its worst. Various kinds of micro-organisms were detected in the water, including numerous "earth" and putrefactive bacteria. Among these were "Proteus" forms, which may be ranked among the objectionable varieties, yet† they are probably antagonistic to the germs of typhoid.‡

The Trenton water, said to be from the hydrant, and stored from the river several days previously, taken by me on the same day at the Pennsylvania Railway Station, had only a few hundred bacteria of five distinct harmless varieties. It was quite unlike the river water in character.

April 27th, 1889 (rainy, river swollen):	Bacteria in 1 c.c.
The usually excellent lake above Delaware Water Gap	1230
Delaware River at Water Gap	3400
" " above Easton	4270
Lehigh " " "	4925
" and Delaware mingled four miles below Easton,	10000 ±
Delaware River at Bridge near Trenton water intake,	20340

* See Report of Engineers Hering and Ludlow, Philadelphia Water Department, 1885.

† Hauser: Ueber Fäulnissbakterien, Leipzig, 1885. Bordoni-Uffreduzzi: *Zeitschrift für Hygiene*, iii, 333.

‡ Karlinski: *Archiv für Hygiene*, 1890, 473.

The following were at the same time collected by Philadelphia Health officer, and carefully kept cool till plated by me after four hours or more:

Delaware River, Philadelphia pumping station....	28000 ±
Schuylkill at Roxborough	43750 ±
" at Spring Garden.....	44456 ±

Under these unfavorable conditions, rivers, even in a sparsely settled region where there is little or no farming, may be expected to show an increase in the number of bacteria as the samples are taken further and further down the stream. This I have observed in several of the rivers of this State and elsewhere in the East, as well as in the Yellowstone Valley this summer on the occasion of a rainfall. Then the river at Glendive had more living germs in each cubic centimeter than were found at Billings, which is over 250 miles further up-stream.

The causes of the large proportion of cases of typhoid in Philadelphia, cannot be traced to any single source of infection. The water supply—if indeed the chief cause—may have received the dangerous germs at any place between the pumping-stations (in sewage-polluted tidal waters) and more or less remote tributaries. It is very difficult to prove that contagion can be carried many miles down a river, and many deny the possibility of this occurring. Owing to the use of contaminated milk by a number of families in Port Jervis, on the upper Delaware, a town of less than 10 000 inhabitants, the place had a slight epidemic of typhoid fever from October 1st, 1883, till the end of the year. No increase in the number of deaths from that disease in Philadelphia was recorded until January, 1884, when the total amounted to almost double the average for the same month during the preceding five years. From these facts one should not infer that the increase of the disease in Philadelphia was caused by the bacteria which had survived the 100 mile passage down the river, especially as in Trenton (which also takes water from the Delaware) there was, as I learn through the kindness of Dr. Ezra M. Hunt, no increase of this disease noted at the time. Still it seems highly probable that the health of the city would be improved, if all its water used for domestic purposes came from a remote location on this fine river, and were then conducted for many miles through an aqueduct. The deeper such aqueduct and its reservoir, the cooler would the water be in summer; and the more moderately cool pure water is, the more wholesome it is for the masses of a city's population.

From the above-given observations it can perhaps be inferred, that

under the most favorable conditions, river water tends to a certain degree to purify itself of infective and other bacteria introduced. Yet the evidence thereby afforded does not seem strong enough to wholly justify such a conclusion. So long as fresh contaminations are constantly entering, the purificative tendency is virtually inoperative. Successive pollutions cause river water to become inferior in quality, as it is tested further down stream, and until after any considerable pollutions have for some distance ceased to enter. The liability to error, owing to unrecognized (and not easily appreciable) contamination of the waters, lessens the value of any tests made with our rivers. Hence, for the purpose of definitively resolving a portion at least of the problem, I have had recourse to a series of biological analyses of the Croton water in different parts of its flow through the magnificent aqueduct which for nearly half a century has so well served this city.* By reason of its superficial passage and of the configuration of the country, the old Croton aqueduct follows a more devious course than the new one. Therefore, and because of the thorough aërification, the old aqueduct (although dark throughout) is (for our purpose) much like an ideal stream, and is admirably adapted for testing the question at issue. The samples were collected at such intervals as corresponded with the flow of the current, which averaged a rate of a little more than 2½ miles an hour. Plates were prepared from the water as soon as it had been taken by means of the usual sterilized bottles.

Water of Old Croton Aqueduct.	Miles from Central Park.	Bacteria per Cubic Centimeter.				
		Dec. 26th, 1889, clear, 39° Fahr.	Feb. 27th, 1890, clear, 37° Fahr.	Apl. 3d, 1890, drizzly, 40° Fahr.	Sep. 30th, 1890, clear, 60° Fahr.	Oct. 11th, 1890, some hours after rain, 58° Fahr.
Sleepy Hollow, Tarrytown	27	....	....	420	372	....
Dobbs Ferry	22	....	453	....	....	....
Yonkers	17	....	283	....	....	....
Van Cortlandt	12	....	292	....	207	405
Bronx inflow, adding $\frac{1}{12}$ or less to volume of stream	....	....	[227]	....	....	....
High Bridge	6	347	266	413	240	377
Central Park (inlet to reservoir)	0	285	175	407	199	302
West side, hydrant	....	229	137	394	215	248
New aqueduct (slight temporary flow)	....	....	....	....	183	....
Surface of reservoir	....	....	....	....	72	143
1 foot from bottom of reservoir [35 feet deep]	....	....	....	....	487±	†
3½ feet " " " " "	....	....	....	....	368±	†

* I wish to indicate my appreciation of the courtesy of the Chief Engineer and his assistants.

† Hydrophore worked defectively, and, that day, the level of the reservoir water was 7 feet lower.

These results must be interpreted as indicating, that under the best sanitary conditions, the number of germs of bacteria present in a flowing water usually tends to become less after a course of a few miles, provided that no new ones have taken the place of those that have lost their vitality. After a single pollution by sewage-matter, introducing bacteria of various kinds, the bacterial contents of a given volume of a flowing water tend to gradually lessen in number. So, the question arises: How is this decrease produced? As factors possibly acting to bring about this result we may consider—dilution, sedimentation (subsidence), concussion, chemical influences (including oxidation), light, heat or cold, and the previously mentioned and admitted antagonistic action of other micro-organisms.

Dilution of the water in which they are living does not kill bacteria; and the fewer existing in a given water, the longer can any harmful ones present probably resist the antagonistic activity of the others. Dilution by a better water lessens, of course, the number previously existing in a given volume. Inasmuch as the little that is known on the subject leads us to infer, that of disease-producing kinds, a considerable number of individual bacteria must reach the vulnerable part of the invaded animal organism before they affect the health, if they do so at all; we may believe that a lessening of the number of harmful bacteria by means of dilution renders water less unfit for drinking, yet does not make it absolutely wholesome, even though causing it to appear relatively so. In the Niagara River, for instance, this element is very important. Having there several times been thwarted by rains and by other causes when starting out to analyze the waters, I received and examined a series of carefully expressed samples which, if they had yielded the same results to examination begun on the river bank immediately after they were removed from the river, would have allowed the inference that the river-water, contaminated by the sewage of Buffalo, became biologically as well as chemically much purer at Tonawanda, 11 miles lower down towards the cataract. Unfortunately the complete immediate examination could not be made. There, as in most rivers, the purification is in great part effected by dilution. In the river water above the falls very many hundred bacteria were found after a rainfall, which there, as in other places, can by surface washing bring in noxious elements.*

* Fluegge (*Hygiene*, 1889, 193) states that *bacillus Typhoid* has been isolated from earth of a field with which typhoid dejecta had "not long before" been mixed. We know that these and other bacteria can, under certain circumstances, live for months in dejecta.
See Grancher et Deschamps: *Archives de médicine* exp., 1889, I, 33.
Uffelmann: *Centralblatt für Bakteriologie*, etc., V, No. 15.

From various experiments* it is known that particles settling in water carry down a notable proportion of the bacteria present. The chemical agents which are at times employed, by uniting with the organic matter present, effect much more than the merely mechanically-acting, weighty particles. Like several other investigators, I have at times during the last two years endeavored to determine whether, in vessels of clear water from 10 to 20 inches deep (also twice in tanks 10 feet deep), bacteria settled to the bottom. The results have been neither uniform nor decisive, yet they seemed to manifest in general a slight tendency to subsidence. In laboratory tests the problem is rendered complex by the jarring of the building, the amount of air and light present, the variations of temperature, and other artificial influences unlike those operative in large bodies of water. The few observations made to test lakes, as by Fol and Dunant at Geneva Lake, Cramer at Zurich Lake, and Prausnitz at Starnberger Lake, do not indicate any great degree of subsidence. Of large bodies of water I have found:

August 28th, 1890:	Bacteria in 1 c.c.
Saratoga Lake, central part, surface	56
" " " " 13 feet down	54
" " 1 foot above bottom, 32 feet deep	163

The few tests here given of the water in the Central Park reservoir, permit the inference that there is there some subsidence of bacteria. Not to consider the larger number found at the bottom (as in only one instance did the apparatus work perfectly), there were considerably fewer on the surface of the middle of this large body of water, than entered through the aqueduct.

Very interesting in this regard are the results attained by G. Frank,† who found that the hundreds of thousands of bacteria regularly detected in the Spree River water, after it had received the sewage of Berlin, continued undiminished till after this foul water had passed into the Havel—a river that then for some miles flowed sluggishly through a series of broad expansions. After a course there of not much over 8 miles, it was usually found that the water taken lower down (from Sacrow) had only a few thousand germs. As this dimunition was, for chemical reasons, not to be explained by assuming an inflow of ground-water, it could be attributed to nothing but a subsidence of the

* Kruger: *Zeitschrift für Hygiene*, viii, 109.

† *Zeitschrift für Hygiene*, iii, 355.

micro-organisms in the lake-like widenings of the slow river, perhaps influenced by the abundant organic particles present. The government health office,* testing similarly the city sewage poured over a large area at the experimental station, found a marked diminution of the bacteria present. There many settled in the still water before it flowed over into the Rummelsburg Lake.

Concussion and movement of the water, I have not found to be followed by any considerable and immediate lessening of the number of bacteria, even in waterfalls† or where powerful pumps force it under great pressure. That harmful bacteria present can, notwithstanding vigorous concussion, produce fatal infection, is obvious from the causation of an outbreak of Asiatic cholera at Southampton, in 1866, resulting in 107 deaths. It was traced by Parkes to the dispersion of infected sewage through the air, by the unusual method of the bursting of many bubbles after the fluid had been churned up by powerful pumping, and in a frothy condition driven along an open channel.‡

That sunlight, as also diffused light, exercises an inhibitory influence upon the vitality of micro-organisms, has been a somewhat prevalent belief since the first report of Downes and Blunt,‖ which incited Tyndall§ and various following investigators. Raum¶ gives a list of many of these. A few, like Engelmann,** state their views that this influence does not arrest microbial growth and movement. The majority, like Janowski,†† consider that light, even in a diffused form, restricts the development and activity of bacteria. In deep waters this factor is of little consequence.

The even temperatures maintained in great bodies of water during the warmer portions of the year, are favorable to bacterial life. The combination of moisture and great warmth, as in the Delta of the Ganges, is considered a potent factor in maintaining the germs of cholera so constantly vigorous that there the disease is always endemic. Cold does not destroy all bacteria, although a certain number succumb to extreme

* Jurisch, Berlin, 1890, page 79.

† Schmelck (*Centralbl für Bakt. und Paras.*, July, 1890, page 102), testing Scandinavian waters, found many bacteria in the ice formed from the spray of a waterfall. Here oxygenation, cold, light and the effects of concussion had all been operative.

‡ Frankland: Proceedings of the Royal Society of London, xxxv, 542.

‖ *Ibid*, xxvi.

§ *Ibid*, xxviii.

¶ *Zeitschrift für Hygiene*, vi, 313.

** Pflüger's Archiv, Bd., xlii.

†† *Centralblatt für Bakteriologie und Parasitenkunde*, August 1st, 1890.

cold. Congelation of the water in which they are living seems relatively favorable to a portion of the pernicious microbes present.* In many serious epidemics it has been observed that in ice and snow the infection of typhoid was kept active for months.

Some chemical waste from manufacturing establishments has a destructive effect upon these low organisms; but such vague and irregular means can itself only be called a pollution of the streams, and is highly undesirable. The typhoid fever epidemic of 1889, at Wilkesbarre, Pa., caused it to appear that the bacilli of that disease were probably unaffected by the commingling of coal-mine water (containing free sulphuric acid and ferric sulphate) with the Susquehanna River water, before this was taken by the water-works of the city.† When intelligently employed in suitable proportions, chemicals render foul water much purer. As a conspicuous instance of this I need only mention the city arrangements at Wiesbaden, by which the sewage is treated with quicklime. It thus becomes odorless fertilizer, and clear water flowing toward the Rhine. Dr. A. Pfeiffer,‡ unlike Fraenkel and others, asserts that, even after this thorough treatment of the sewage, from one-fourth to one-third of the bacterial germs remain alive in the water! If this be so, no acids or bases present in ordinary water are of any disinfectant value. Certainly the small amount of carbonic acid found in streams can devitalize no bacteria. Hochstetter‖ and Fraenkel§ found that by the action of this agent only a few varieties were markedly affected, and that nearly all the harmful ones could live in carbonated waters for days. My own observations have been to the same effect.¶

The presence of a small quantity of mineral salts, as in the various mineral waters, has no notable influence upon the number of bacteria present. In all kinds of bottled waters from all parts of the globe living bacteria may be found, unless these waters have passed through a sterilizing process. Of the numerous waters flowing from the well-known springs in the Saratoga Valley, I have found that some were wholly sterile, while neighboring ones of like saline ingredients had hundreds

* Prudden: *Med. Record*, March 26, 1887. Bordoni-Uffreduzzi: *Centralbl. für Bakt.*, 1887. Fränkel: *Zeitchr. für Hygiene*, i, 2, 302.

† Breneman, *Jour. of the Am. Chem. Soc.*, xii, No. 1.

‡ Deutsche *Vierteljahrschrift für öffentliche Gesundheitspflege*, xx, 55.

‖ Arbeiten aus dem königlichen Gesundheitsamte, Band ii.

§ *Zeitschrift für Hygiene*, v, 333.

¶ *New York Medical Record*, xxvii, 680.

of living bacteria in each cubic centimeter, the determinations being made immediately after the water to be tested had issued from the ground.

Oxygen is everywhere present in the atmosphere in such abundance that, even in city streets, its proportion does not fluctuate more than $\frac{1}{2}$ of 1 per cent. from the normal 78.3 per cent. contained in the purest air. Of this atmospheric air, somewhat less than 2 per cent. of the volume of a mass of water is taken by the water. This fact is the foundation for a satisfactory explanation of a great part of the actual lessening of the number of bacteria in a flowing stream. They may be assumed to perish, in the active exercise of their function of causing the organic matter to oxidize. When this impurity is in the form of the organic matter occurring in sewage, the process of oxidation is a much more active one than with the *humin* substances found more prominent in purer river waters. It can hardly be claimed that ozone is ever present in these waters in sufficient quantity* to act as a disinfectant. The same may be said of peroxide of hydrogen which, in the laboratory, as we may believe from the experiments of Altehöfer† and others, destroys *B. typhoid* and all other bacteria exposed for twenty-four hours to a 1.1000 solution of this in water.

We lack more precise knowledge than has been indicated by the references already made in this paper, concerning the antagonistic action of the various putrefactive and other bacteria upon the pernicious varieties. All that can be said is, that at least some of the various disease-producing kinds perish, or fail to increase, when the ordinarily-occurring varieties are abundantly present. Yet some harmful species may thrive, despite the presence and activity of common bacteria which suppress the less hardy of the harmful ones.

Summary and Corollaries.—While our knowledge of the causation and intimate processes of disease is at best very limited, and while telluric and other conditions exercise, upon our states of health and illness, influences not as yet comprehended, recent progress in biological science has caused us to know more and more about the origin and extension of various infectious disorders. In view of bacteriological explanations, we cannot doubt the potency of polluted water in inducing the

* Kowalkowsky, *Zeitschrift für Hygiene*, ix, 1, page 89.

† Altehöfer: *Centralblatt für Bakteriologie und Parasitenkunde*, July 25th, 1890, page 136.—Van Hettinga Tromp: Waaserstoffsuperoxide ter Desinfectie van Drinkwater, 1887.—Uffelmann: Jahresbericht, 1888, 47.

diffusion of some infections, and notably of typhoid fever. Like other harmful germs, the characteristic bacilli of this disease can live for days in water whose gross appearance is that of purity, and in which only the biologist can detect the impurity, although the other micro-organisms, such as are nearly always to be found in natural waters, tend to destroy the pernicious varieties.

There exists in all streams a capacity for at least partial self-purification after sewage or other pollution has entered. Biologically, this is manifested by a lessening of the number of bacteria present after several miles of flow, in case no fresh accession of inferior water occur. The pernicious varieties probably lose their harmful character, or when not excessively abundant are so diffused throughout as to be virtually harmless. Dilution seems the main factor in inducing this improvement, but oxidizing processes are of considerable importance in purifying waters. In rivers with very slow current, or in lakes, probably some bacteria settle. They unquestionably do so when the state of the water is such as to induce sedimentation. The application of this principle has produced beneficial results in the water systems of certain cities. "Antagonisms" among bacteria, shorten the life of disease-producing germs in waters where other (presumably harmless) kinds abound.

The excellent water supplied to New York is somewhat improved by the long flow through its aqueduct; yet too great care cannot be taken to keep the Croton watershed as free as possible from all habitations and industries. Only by vigilant and intelligent efforts can lasting and constant purity of the supply be maintained. Especially on summer days and during the time of high dry winds would it be advisable to more assiduously moisten the dusty and much frequented walks and roads about the Central Park Reservoir, as the deposit of much undesirable dust and accompanying bacteria in the water (shortly before its distribution throughout the city) could thereby be prevented.*

It is more economical and much safer to prevent contamination, than it is to use filters when the water has become dangerous. Large filters, when very carefully managed, effect a great improvement in

* When moistened, bacteria and the dust which is the usual means of carrying them through the air, remain upon the ground where they may have fallen. Unclean dust can be carried very far; but I will here only intimate that the excessive filth of our streets will be sufficiently remedied only when our greater and lesser lawgivers are made to realize the importance of cleanliness in every sense of the ill-understood word. Unclean streets and dwellings among the poor can cause disease among the opulent. The filthiness of individuals can endanger the health of the many.

inferior waters;* but they do not prevent all disease germs from passing through.†

It would be a most prudential act for the State to restrict the present devastation of its fine woodlands, and we should encourage the planting of at least one tree for every one hewn down. Forests afford a very valuable means of water-storage at the fountain-heads of our streams, and aid greatly to preserve the desired constancy of flow.

Inasmuch as impure water probably causes disease oftener than we can demonstrate, and as there is, unfortunately, an immense body of irrefutable proof of its frequent harmfulness, all suspected water—and this especially at time of an epidemic—should, like all other foods, be cooked. Concerning such liquid foods as water and milk, it may be said that a very brief boiling,‡ makes them free from the infective property which they in an uncooked state might possess.

APPENDIX I.

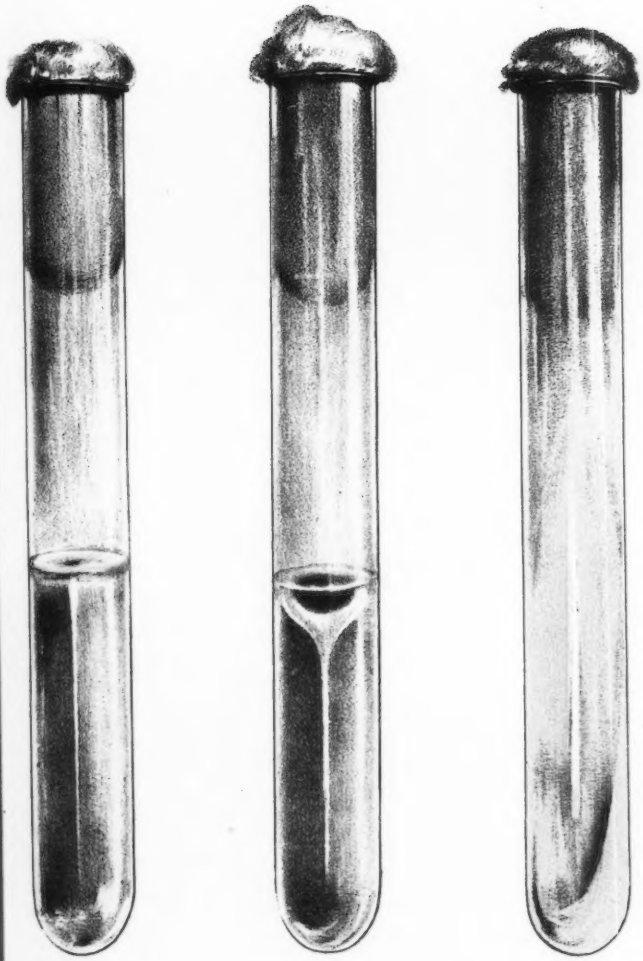
Into test-tubes, such as are shown on Plate IV, we place a very nutritious bouillon rendered solid by the addition of 10 per cent. of gelatine and then steamed long enough to kill any germs which might be living in it. This becomes fluid as the temperature rises above 73 degrees Fahr. If to it in this softened state a few drops of average water be added and the mingled contents of the tube be poured into a shallow glass dish, the mass solidifies after a little while unless kept warm. The individual living bacteria which were in the added water are thus distributed singly throughout the even layer of the solidified nutrient gelatine, and in a few days each of these micro-organisms (perhaps less even than $\frac{1}{25000}$ inch in size, and usually not over $\frac{1}{5000}$ inch in length), has multiplied so enormously that we see in it, and upon the surface, spots varying in size from that of a pin-point, or smaller, to even that of a coin, and composed of many thousands or of millions of individuals. (See Plate V.) These are called "colonies." Their appearance varies greatly, and thereby in part we recognize different species. To study these further and distinguish species, we take a piece of platinum wire 2 inches long and fixed in the end of a glass rod, the whole having been passed through a flame to devitalize anything that might be upon it. We lightly touch the tip of the wire to one of these colonies and then pass the tip over the surface of (or into) various "culture-media" (such as potato, agar, gelatine, etc.), contained in test-tubes and which

* Currier: *Medical News*, April 27th, 1889.

† Fraenkel: *Deutsche Medicinische Wochenschrift*, December 12th, 1889, pages 1023, 1025.

‡ *N. Y. Medical Record*, June 14th, 1890; *N. Y. Medical Journal*, June 21st, 1890.

PLATE IV
TRANS. AM. SOC. CIV. ENGRS
VOL. XXIV Nº 463.
CURRIER ON
SELF PURIFICATION OF WATER.



After 30 hours

After 100 hours

Koch's Cholera Spirilli in gelatine.

Oct. 29th, 1890.
C. G. C.

Typhoid Bacilli
Third day of
growth on Agar.

PLATE V
TRANS. AM. SOC. CIV. ENG'RS
VOL. XXIV Nº 463.
CURRIER ON
SELF PURIFICATION OF WATER.

Oct. 29th, 1890.
C. G. C.

Croton water ¼ C. C. added to gelatine, and seen on black background. Natural size, third day.

Water Bacteria from one of the constantly occurring, whitish-buff, liquefying colonies, colored with methylene-blue and magnified more than 2250 times.

(Zeiss' "Homogene Immersion", 2.0 M. M. aperture, 130 and ocular No. 18.)

have previously been sterilized by moist heat. In a few days the different varieties of bacteria have caused peculiar and distinctive growths to appear. If a minute portion of one of these is spread on glass and viewed through a high power of the microscope, it will be seen that the growths are composed of very many minute bodies which are bacteria. Some bacteria—as, *e. g.*, the variety characteristic of consumption (*Bacillus tuberculosis*) and those which thrive only in the absence of oxygen—have to be studied in other ways, yet this sketch indicates the general principles of the Koch method of determining the number and varieties of water-bacteria present in a given sample.

APPENDIX II.

The Efficacy of Filters and of Other Means Employed to Purify Drinking-Water.

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*A Bacteriological Study.**

By Charles G. Currier, M.D.

Water, even after having been exposed to various chances of contamination, is very generally drunk as it is received from lakes or rivers, wells or springs, tanks or hydrants; and, despite the most disinterested warnings, people are not ready enough to believe that clear, sparkling water may at times be the most harmful of beverages; that it can carry with it, and introduce into the systems of a portion at least of those who drink it, the immediate causes of various impairments of health. Polluted water may be agreeable to the taste and have no visible sediment, yet cause many deaths. Such water the unskilled are slow to suspect, and but for the advance in sanitary science, and the warnings conveyed by those familiar with hygienic studies, pure supplies of drinking-water in cities would be much more of a rarity than they are.

At the Hygienic Congress in Vienna, in 1787, M. Brouardel stated that he knew of over sixty epidemics of typhoid fever which had been induced by the drinking of infected water. From typhoid fever thousands of deaths occur every year; and, although scientific physicians are constantly urging these facts, it seems to be necessary that the danger present itself in the form of an epidemic before the people fully realize the immense harm which may result from impure drinking-water. The epidemic which ravaged Plymouth, in Pennsylvania, four years ago, attracted great attention at the time, but the history of several similar

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* Read before the Section on Public Health of the New York Academy of Medicine, April 5th, 1889.

Condensed from *The Medical News*, April 20th and 27th, 1889, where some of the bibliography can be found.

"visitations" since then, would indicate that the full value of this severe lesson has not been properly appreciated.

Water may be very highly colored, and yet, if freshly collected near its source, show no very large number of bacteria. Such is the case with the best of the peaty "juniper" water which I have examined in various parts of the Dismal Swamp of Carolina and Virginia. Although having a large proportion of organic matter, this water is reputed eminently wholesome, and an inquiry among a portion of those drinking this exclusively, appears to show an unusual degree of immunity from the manifestations of diseases which might be attributed to the effects of improper drinking-water. If harmful bacteria be introduced into it, such water favors their increase, while they would not be so apt to multiply in a very pure water having much less organic matter. Despite the good reputation which this water has had, and its wholesomeness near Lake Drummond, one who has seen the whole length of the canal down to the lower end, from which the supply for vessels is taken, can realize that the water may undergo considerable contamination before it reaches that part. I am sure that the present use (in our navy) of distilled water, kept in proper receptacles, is safer than the employment of the swamp water. On the other hand, the turbidity which is common at this season of the year in the streams furnishing the water supply of many of our cities, is almost always accompanied by a large number of bacteria. The melting snow and the rain, which wash into the streams an increased amount of organic matter, introduce with it other germs (perhaps pernicious), and bring more nutriment than usual to the micro-organisms already in the water.

It is believed that, like most of the varieties of bacteria found in water, the still larger forms of animal and vegetable life, ordinarily existing in lakes and rivers, are not prejudicial to health. It is through the products of the decomposition of many of these, when their life has ceased, that they may become harmful.

Chemistry has long furnished a means of recognizing polluted water, even when it yielded no sediment visible to the unaided eye; and the presence of considerable quantities of chlorides, nitrates and ammonias, determined by the chemical tests, has shown that many a water had more organic impurity than was considered desirable; and, when far below the accepted standard in this respect, such a water is justly condemned. Yet it seems as though enough of the infective element of cholera or typhoid to diffuse an epidemic throughout a community can be added to a drinking-water, and not be detectable by chemical tests. A perusal of the very complete and instructive paper by Professor J. W. Mallet (in the report of the National Board of Health for 1882) shows how widely such determinations may vary, and how unreliable chemical standards may be. We are thereby made to recognize that a close acquaintance with the entire watershed, is of greater value than a mere chemical determination.

The known disease-producing bacteria, however, do not appear to increase in water in which there is not more organic matter than the proportion that chemists of constant and large experience regard as permissible in waters which they pronounce to be of fair quality, although these harmful bacteria, if once introduced there, may long retain their vitality and remain dangerous. In my tests, when I prepared an artificial water, I added the germs directly from a pure culture, unlike Bolton, and like Wolffhügel and Riedel (Arb. aus d. Gesundheitsamte, 1886, i. p. 455), with whose results, however, I cannot so well agree as I can with those of Bolton (Ztsch. f. Hygiene, 1886, i. p. 76). I have in

but two out of many trials, with disease-producing species, found typhoid bacilli to increase in sterile pure water, and then only to the extent of 30 per cent. In the Croton when it was sterilized, I have been able to keep typhoid bacilli alive for only two weeks, and usually not over eight or nine days. I have observed that the greater the variation of temperature it was exposed to, the shorter time did this micro-organism live in water.

Since, as yet, chemistry, when called upon to aid in solving the question of the purity of a water, can at its best only approximately estimate the amount of organic matter present and its state of oxidation, while it fails to inform us whether infective matter be present or not in a given water, it has been hoped that a sure means of recognizing whether a water be in any degree infected was reached, when Koch introduced the bacteriological test. This test, while very definite and conclusive under favorable conditions, has thus far been able to decide absolutely, in only a small portion of cases of disease apparently coming from the use of drinking-water. Yet in those cases where the bacteria characteristic of distinct disease have been detected in the suspected water, the isolation, culture and identification of the disease-producing species, furnish a convincing proof of the great value of the method.

The method employed is a simple one. Usually 1 cubic centimeter of the water to be tested is added to 10 cubic centimeters of nutrient jelly, made by solidifying very nutritious beef tea by the incorporation of one-tenth its weight of gelatine. Everything being done with rigid precautions, the water to be tested is added to the nutrient jelly, which has been softened by being warmed to a little more than 30 degrees centigrade. This is then quickly mixed and poured upon a cooled glass plate, where the fluidified gelatine soon becomes quite solid. Then the germs in the water, being scattered evenly throughout the mass, exercise their functions of rapidly multiplying at the room temperature; and, in the nutritious medium, the minute microscopic individual has perhaps by the third day become a dot as large as a pin-point, or much larger, containing thousands or millions of newly-formed bacteria. These are called "colonies," and vary considerably in appearance, as will be seen by comparing the plates made with various waters. With a glass ruled into centimeter squares the number can be counted or estimated. If a large number of thousands be present, as in waters artificially prepared for tests and in sewage contamination of water, the only way to arrive at an accurate estimate is to employ in the eye-piece of a microscope a micrometer square. After determining the number we isolate and identify the species as in general bacteriological study.

There are many features of the subject which must be omitted in a paper of this scope, for they may not interest all, and I will not linger over the still unsettled question as to the absolute value of mere numbers of ordinary water bacteria in determining the sanitary merits of water.* It is, however, admitted that the fewer the varieties present, the less is the likelihood of sources of contamination affecting the water. In examining a considerable number of samples of water from various sources, I have observed that the less chance of contamination there was, the fewer bacteria have I found in the waters. Thus, fine mountain lakes and springs have never in my experience, unless under very un-

* Gärtner: Correspondenz Bl. d. allg. ärzt. Ver. von Thüringen, 1888; Nos. 2 and 3.
Centralbl. f. Bakt. und Par., iii, 5, p. 161 *et seq.*
Wolffhügel: Arbeiten aus dem Gesundheitsamte, Band i., iii. 5 Heft (1885), p. 546.
Plagge und Proskauer, Ztschr. f. Hygiene, 1887, pp. 470 and 486.

favorable conditions, shown as many as one hundred bacteria in each cubic centimeter, while the same quantity of water, from a river draining thickly peopled valleys, may show more than fifty times as many. While it offers less striking extreme differences than I have seen in the Hudson Valley and elsewhere, the Passaic water-shed may be briefly instanced as illustrating what I have just said. I give it because it is the smallest one near us offering every phase of importance in this connection, and because the subject of a supply to come to New York from that source, has been seriously considered. The best of the upper lakes of this system showed on a pleasant day of the past winter, only fifty-seven germs developing in the nutrient gelatine; the Pequannock and other tributaries into which these lakes flow showed, in the samples collected as nearly at the same time as possible, over three hundred and fifty germs, which number increased as the water was taken further down stream; while at the Passaic Falls, in Paterson, over a thousand were detected in each cubic centimeter. Water from a hydrant in Newark, at the same time, showed nearly four thousand germs of bacteria in each cubic centimeter. The Newark water supply is at present derived from the Passaic, some miles below the place where sewage from Paterson is discharged into the river.

As in chemical, so in bacteriological water examinations, those who have had the broadest experience and who are most careful are best in a position to pronounce an opinion. Apart from any personal equation, there are still limitations to the entire comprehensiveness of the method. I may mention that bacteria are recognized as present in the human body and in its products and changed tissues, which bacteria are never found to live on the gelatine or other water plates. Then, too, a water may be submitted for examination when all the obvious infection has disappeared, or has become exceedingly diluted, and hence a most painstaking test, then fails to reveal the presence of the characteristic microorganism. The period of incubation, after the infection and before the symptoms are recognized, may in Asiatic cholera occupy the greater part of a week, and in typhoid often lasts for two weeks or more, so that all traces of the harmful bacteria may have left the water before it is suspected. By reason, also, of its likeness to various harmless species, and its tendency to be overwhelmed by other more rapidly developing forms, the "colony" of the disease-producing species may be hard to identify. In this respect typhoid is decidedly more difficult than cholera to recognize in ordinary water.

For those who believe that bacteria of certain kinds living in water, and with this introduced into the alimentary canal, can in many cases induce disease; this test, being so precise and delicate as it is, must appear the best way of determining whether the filters and other means in common use are efficient, or otherwise, in removing the dangerous elements from impure water passed through them—in short, whether they act as "disinfectants" of the water.

As various other agencies are used in conjunction with, or as supplementary to, filtration, it is proper that I here indicate how far they serve to purify drinking-water. One of the most prevalent means directly resorted to for this ostensible purpose, is the admixture of wine (usually red). Adding this to an equal amount of Croton water, I find that a varying proportion of the bacteria are killed, sometimes less than half, even after the mixture has stood for days. The spirituous alcoholic beverages (having from 45 to 68 per cent. of alcohol), mixed with Croton hydrant water in equal parts, cannot be depended upon to kill all the bacteria, especially when "earth" bacteria are present, and a

small percentage of whisky (less than 20 per cent.) has very little effect in this direction. In malt liquors, as lager beer, the prolonged boiling in the brewer's kettle has destroyed the bacteria of the original water, even if they be of the most harmful and resistive species which we meet here. Various kinds, however, if present in vats, kegs and bottles, (because of imperfect cleansing), will live in beer. Almost all the artificial mineral waters that I have examined are made of unsterilized water. Pressure of carbonic acid gas, and contact with it for days, reduces greatly the number of bacteria in a mineral water, yet the typhoid bacillus and others will live for days in seltzer water and similar waters. In New York I have found many bacteria in the few carbonated beverages that I have examined. Peroxide of hydrogen, one part to one thousand of water containing harmful or harmless bacteria, destroys these in twenty-four hours. Yet this is an unstable compound which will not gain much usage.

Of the various acids which it is occasionally safe to employ, chemically pure hydrochloric acid must be used in the strength of at least one-half of one per cent. to destroy all the germs in Croton water to which *B. subtilis*, *B. typhoid* and other bacteria have been added; and may fail to sterilize the water even after hours of standing thus acidulated. Sulphuric acid is more than twice as potent, and usually in the strength of one part to five hundred of water, will render this free from living germs. Sometimes, however, it has to be used still stronger, as it is in a certain extensively advertised nostrum, in which, under a fanciful name, it plays the principal part. Alum, lime and the other chemicals which, by inducing sedimentation of organic and mineral constituents, carry down many of the bacteria in water, do not (as is often believed) insure the annihilation and destruction of organisms present. It is the mechanical action of the film, which the presence of a minute amount of these causes to settle sooner than would otherwise occur upon sand in certain large sand filters, which insures their excellence, and the scarcity of bacteria must here not be attributed to a coarse chemical action. When chemicals are added in sufficient strength to destroy speedily all the bacteria which may be present, the water thus treated cannot be recommended as a beverage.

With the imperfection of all other methods, we have in prolonged boiling a sure disinfectant of any water. I have usually found that maintaining a water at the boiling point for even less than fifteen minutes, sufficed to prevent any of its germs from developing in gelatine, and this even with bad waters from sewage-infected rivers. The process of distillation likewise sterilizes water.

The germs of cholera and typhoid are very sensitive to heat, and boiling heat kills them at once.

That freezing temperatures destroy only a certain proportion of the bacteria which exist in the water from which the ice we use is formed, has been established by, I think, repeated observations. I will simply warn against putting ordinary ice into water which we are to drink, as many kinds of bacteria may be thereby introduced. Ice made of distilled or boiled water is wholesome.

The mechanical separation of impurities is the principal action in all filters, whatever their composition. The amount of oxidation produced by the passage of considerable quantities of water through inconsiderable masses of charcoal, sand or anything else, seems never sufficient to chemically purify an infected water, although the Berlin system of filtration, by large beds of sand skillfully managed, effects a notable improvement in this respect. In some cases the nitrifying bacteria

present appear to produce a noteworthy improvement. This element will be spoken of later on.

Almost all tissues tend to separate visible particles from water which is turbid, or in which a deposit settles. The fact that such matter is retained from the water passed through filters, appeals very strongly to most persons; and the general assumption that such visible matter is dangerous, and that its removal insures the purification of water, seems to explain the extensive use of filters. They are all composed of felt-like matter (filtrum), or of any tissue or substance so woven, composed or arranged, as by its structure to more or less completely arrest the passage of sediment and the floating particles existing in varying amounts in nearly all natural waters. The filters in domestic use may be arranged in two classes. In one class the water runs or is poured into a tank, or other receiver, over or beside some filtering medium, through which the flow is into a receptacle, and from this the water is taken as needed, or is stored as fit for drinking. Those of the second variety are designed to connect with the faucets, and to strain from the water such impurities as it brings through the hydrant.

One of the most widely used varieties is a portable one, which renders water clearer and more agreeable to the eye. It is composed of a cylinder of pressed carbon, 3 inches or less in diameter, and having nearly the same depth, which has from its interior a tube passing through the bottom of the funnel in which it rests, thus requiring all the water passing out of the bottom of the funnel to go first through the mass of carbon. The flow is very sluggish unless use be made of pressure or suction, as, for example, by lengthening the tube taking water out of the filter. This, by hastening the action, impairs the effectiveness so far as purification of the water is concerned. After this has been used for a few days, the retardation is very marked, due to the clogging of the filter by the various matters which form the sediment of the unfiltered water. This necessitates frequent cleansing.

Taking a freshly sterilized carbon filter of this sort and pouring into the funnel Croton water just drawn after considerable has run from the faucet, and then collecting in sterilized test-tubes the first flow from the filter, adding of this (as already explained) one cubic centimeter to ten parts of softened nutrient gelatine, the mingled gelatine and water being poured upon a cool plate, it is seen that, before three days have passed, several colonies have developed. Comparing the number of these with that found from the original Croton water plated just after being drawn, we find that at least from 5 to 8 per cent. of the bacteria pass through the filter and develop. The percentage rises as more and more water flows through. From fourteen trials made with simple Croton water, I found that through a carbon filter, freshly sterilized and the introduction of germs from the air and other sources of contamination being guarded against, the first flow showed only a small percentage of the bacteria found in the original water used. Then I continued the use of the same filter without resterilizing it, and endeavored in every way to have the conditions under which it was tested as much as possible like those which would exist in domestic use, and the supply of water in the funnel was allowed to become exhausted at times, as usually during the night. In this filter thus used, the number of bacteria in the water passing through is, on the second day and thereafter, much larger than in the water taken after being poured into the funnel and before it has percolated through the carbon block. This excess, when large, seems to bear an inverse ratio to the volume of the flow.

It is a familiar fact that, if fresh hydrant water in a flask covered with cotton (to prevent the entrance of bacteria from the air) be allowed to stand for a day at the temperature of the laboratory, the original bacteria in the water may be found to have increased considerably. So, as a collateral test, after water had been poured into the filter and before it had passed through the carbon, I have taken some of this original water and allowed it to stand in test-tubes and flasks, both stoppered and open, by the side of the filter similarly protected from the entrance of germs from the air, and exposed to the same variations of temperature.

This water, examined at the same time with that coming out of the filter, showed that the bacteria appear to multiply much more rapidly in the substance of the filter than outside in separate flasks, kept at the varying temperature of the laboratory, as it then was. The water poured in rarely contained as many as 225 bacteria in each c.c., and yet in from one to three days from the time when the freshly sterilized filter had begun to be used, the water after passing through the carbon showed several thousand in every case, and at times more than 25 000 bacteria in each c.c.

All sorts of bacteria appeared to pass through, and not alone water species. The bacillus of typhoid fever will not only pass through, but in two of my trials I found that it had increased. For such special tests I used sterilized Croton water, into which bacteria were introduced from pure cultures. For artificial typhoid water, the bacillus of typhoid was added from agar and potato cultures. Harmful bacteria can pass through such filters, can possibly increase in them under certain favoring conditions, and from parallel tests, seem to retain their vitality longer when in the substance of the filter than when in a glass vessel beside it.

Clean sand fairly represents the granular masses of filtering material, and has all the advantages of powdered charcoal and magnesia as generally used for filtering considerable quantities of water, while it is more readily cleansed of the accumulated organic matter, and, unlike spongy iron, adds nothing objectionable. Unless, as in the case of the large Berlin filters and others acting similarly, rendered more effective by overlying silt and organic matter, beds of sand do not prevent the passage of large numbers of bacteria. I have found many bacteria in waters from various artesian wells coming from a deep stratum of sand, though the best ground-waters are very free from these. Through a thin sterilized layer, from 6 inches to 1 foot in depth, of the finest sand procurable from beaches, all the way from 40 per cent. to 95 per cent. of the bacteria in the original water pass, even when the level of the water is never more than 3 inches above the surface of the filtering mass. When a higher pressure is afforded by the water, very few of the bacteria are kept back.

As in nearly all other filters, so through a layer of sand, all kinds of bacteria, harmless or harmful, appear to easily pass. Here, too, they can multiply in the moist sand. Thus I have found the hydrant water, which entered the sand filter with 290 bacteria in each c.c., to come out through the filter (not freshly sterilized before using) with sixty and one hundred times as many as entered. In a gram of sand taken from a filtering bed, I have found more than 10 000 bacteria.

The combination of other substances with sand, as in numerous small and large filters, fails to improve the usefulness of either, except in so far as the elimination of sedimental and other coarser particles is concerned. Sponge is often employed for this purpose, as well as independently, yet it is incapable of separating bacteria from the water strained through it simply, or through sand or other substances used

with it. When a large mass of fine sterilized sponge is closely packed, the first few ounces of hydrant water that pass through may have a very small percentage of bacteria, but the proportion soon increases; while if the sponge-mass be considerable and loosely packed, it may, even in the beginning and under exceedingly slight pressure of water, keep back no more than 15 per cent. of the bacteria of the original water. This freshly sterilized sponge can, at the end of the first day of ordinary use, cause the water then flowing through it to contain ten times as many bacteria as the Croton water poured in. The stronger the pressure, and the more rapid the flow, the lower is the ratio of excess due to increase in the filter over the quantity found in the unfiltered supply, which, of course, was here, as in all other tests, regularly plated at the same time with the filtered water. When the flow is sluggish, and when it stops entirely at times because of all the water supplied having passed through, the sponge substance favors the increase of the bacteria to a greater extent than is the case with sand. The sponge, within twenty-four hours after sterilization, may, under these conditions, cause the water first running through after the intermitting of the flow, to have five hundred times as many bacteria in each cubic centimeter as are found in the water supplied for filtration.

The only way really to cleanse such a filter, is to remove the sponge and boil it. Then the process repeats itself. In a few hours after unsterilized water moistens it, the mass of sponge is again teeming with bacteria. Sponge filters are, so far as I have seen, becoming less popular. It is easily recognized, even by an untrained observer, that the organic matter in sponge can undergo decomposition under the conditions obtaining in ordinary filters. Several of the large filter systems used in manufactories, hotels and other places where large amounts of strained water are used, employ sponge, and the filtered water abounds in bacteria. Filter paper, as used in laboratories, is useful in separating precipitates and sedimental particles from water, but at least from 50 to 70 per cent. of the bacteria in Croton hydrant water go through with the water filtered, even if the pressure be exceedingly slight. The paper which I employed in the trials was, of course, carefully selected, and the folding was cautiously done, so as to prevent any break in the substance. Only single sheets were tested.

"Prepared cotton," cleansed as for surgical dressings, and so made absorbent, removes considerably fewer of the impurities of the water than does the filter paper. Two-thirds of the bacteria pass through when the cotton is at its best, freshly sterilized and carefully packed. If enough be used, it will usually render the water clear; but, as it has been lauded as a filter, I ought to add the statement of my observation, that when left moistened with water, as in the intervals of filtering through it, the bacteria of the original water can multiply over one hundred and fifty times, and all kinds can pass through it.

Combinations of the various substances mentioned have hardly any enhanced merit as strainers, and, as far as the bacteria are concerned, the combination seems to add no safeguard. Sand with carbon (bone charcoal) and sponge or cotton, hold back at first a larger percentage than sand would by itself. Yet bacteria pass through in any case, and the increase afterward is greater than in simple sand. This I have seen in various filters.

In well-known establishments of New York, where immense quantities of artificial waters are prepared every week, all the water used in their preparation is supposed to flow through a layer of fine sand in the bottom of enormous vats, and from the receptacle into which it then

flows, it passes through a layer of charcoal. These layers are each less than a foot in thickness, and water passes rapidly through. The sediment is thereby removed, but in the examinations which I have been enabled to make, I found that each cubic centimeter of the filtered water had over 2 000 bacteria on each of the plates made, while the Croton taken from the hydrant in the immediate neighborhood averaged never over one-eighth as many.

Asbestos of the best quality, new, freshly sterilized and tightly packed, I have found capable of holding back all bacteria when the pressure of the water was low, and the few that were forced through when the substance was defective, did not seem to multiply so rapidly as in other filter masses. While it, when of the best finish and most tightly compressed, deserves to rank next to the principle employed in porcelain filters, these latter are superior in that they can be regularly furnished of a uniform and definite quality which produces the best results, while it is difficult to keep the best asbestos boards up to their original standard of excellence; and if the surface be large enough to insure an abundant flow of water, flaws are liable to arise, and these let various bacteria through. With asbestos it is the fineness of the surface which the original water encounters that is important, more than the thickness of the layer.

Although wire cloth strains out the coarser particles, its structure does not cause the removal of any of the bacteria from water passing through. Still it has the positive merit of being easily cleansed, and can be heated in an oven or boiled to sterilize it. Furthermore, it does not furnish a filter mass for the bacteria to multiply in. although harmful bacteria can adhere to it, and become dangerous, if it be left uncleaned.

Closely woven cloth (such as thick, dense flannel), when only a slight pressure is exerted by the water, may stop 10 per cent. of the bacteria in the water poured upon it. It is easily cleansed and, if very often changed and boiled before using, serves excellently as a simple strainer, without the disadvantage in this respect of ordinary filters, in whose substance the increase of bacteria may be enormous.

Like porcelain, filters of porous stone (if of the best quality), prevent the passage of bacteria with the water filtered through them just after they have been sterilized. To test porous stone, I employed selected perfect specimens of a popular filter which very satisfactorily clears all turbidity from as bad a water as that of the Hudson River, at its worst. In these, the stone layer was cemented into a porcelain cylinder, and was about ⅜ths of an inch in thickness. The pressure was never more than that of 10 or 11 inches of water, and, at the fastest, less than ⅛ths of a liter passed through in an hour. As the sediment of the water settled upon the surface of the stone, the flow became much slower. During twenty-six trials of this kind of filter, it had previously been sterilized ten times by exposure to moist or dry heat, or to both, for several hours. In every one of these ten cases the various waters poured into the receptacle above the porous stone for the first time after sterilization, flowed through germ-free; that is, the stone was permeable for water, but at first allowed no bacteria to pass through, and the plates of gelatine developed not a single colony from the usual cubic centimeter of the filtered water. After some hours of use, a few bacteria had insinuated themselves into the stone or were drawn through with the water. Within twenty-four hours the water flowing through and collected in sterilized receptacles contained many bacteria, which numbered regularly from seven to fourteen times as many as were in

the original hydrant water supplied during these trials. After several days, the number of bacteria had so multiplied in the stone, that the first water running through after the stone had remained for several hours without any flow through it, (as happens constantly over-night in domestic use), showed in each cubic centimeter of this filtered water over one hundred times as many as the average water poured in for filtration. To further test these filters, I have used artificial waters made by adding bacteria of all shapes and characters (from pure cultures) to Croton water sterilized by boiling. These various kinds can get through, but the disease-producing and spiral forms usually died out in large numbers before any could pass. From Croton water, the most marked by its predominance in the filtered product, was a short, mobile bacillus, which was unlike the two varieties first forced through the porcelain in my experiments.

Allied to the porous stone filters, are those of porous porcelain prepared in this country. Porcelain baked at the same low temperature as the porous cups used in electric batteries is, in its efficacy, very much like the stone just described. Under a low pressure, water passing through this substance during one or two days can become completely sterilized, which is a result superior to that got from the stone filters. Before much water has passed, the bacteria make their way through and multiply somewhat on the passage. This material, as I have thus far found it, of American manufacture, is therefore imperfect, yet it is superior to rebaked porcelain, in the single important respect that it is not brittle, while the rebaked porcelain cylinders of the Chamberland-Pasteur filters are quite fragile.

It has for some time been known that fluids can be rendered germ-free for laboratory use, by being passed through solidified plaster of paris (best prepared with incorporation of asbestos shreds). These filters, however, lack permanency, and cause the objectionable sulphate of lime to be present in the filtrate.

Recognizing the defects of other substances, Pasteur and Chamberland called attention to their filtering cylinders, in which the important element is unglazed, rebaked porcelain. Originally employed to facilitate "cold sterilization" of fluid culture media, the fact that water went through the porcelain without carrying any bacteria with it, has caused attempts to popularize its use. Inasmuch as some bacteriologists on both sides of the Atlantic had reported that this filter prevented the passage of bacteria, I was careful to use only selected cylinders without flaws, and did not omit any precaution to prevent the introduction of contaminations.

The most satisfactory way of using this for testing was to employ the single porcelain cylinder, within the usual casing, attached to a hydrant system and with a pressure of water varying from 6 to 15 pounds. Even with the highest New York hydrant pressure the flow is only drop by drop. It can be used to siphon water out of a jar, and in this way it works nearly as rapidly as when attached to the hydrant, in the basement of a house, in the center of this city. By a porcelain cross-tube sold in Paris, two or more cylinders can be siphoning at the same time into the same tube. To avoid risk of contamination, I used for siphoning a single cylinder, to which a bent glass tube was attached by a tightly fitting piece of rubber pipe, all parts having been sterilized, as well as the water by which the flow of the siphon was started. I got germ-free results regularly by this means in seven trials with two cylinders used separately; but, in order to insure this, all the precautions mentioned are necessary, as, in the water siphoned in domestic use of

these cylinders, bacteria of various sorts are found, yet they are possibly contaminations due to the inherent defects of all such joints as are used. So I have devoted more time to testing these when directly connecting with the hydrant, as very slight precautions are needed, in their use with faucets, to eliminate all chances of contamination.

My first thirteen trials of this filter used in this way were under less satisfactory conditions than the fourteenth and those following, as the former were in a laboratory where the available water came under not much more than 20 feet pressure from a tank, and I was not able so well to control the constancy of this pressure as I was during the later trials. My first sixteen tests of various ones of these cylinders gave sterile water. Then, attached to a basement faucet, with a direct flow from the hydrant under a pressure never exceeding 15 pounds, (except that on Sunday nights it was for a few hours 3 pounds higher), the filter, after several days of intermitting use, gave over 3 500 bacteria in each cubic centimeter, and all the water examined (two samples per day) for four days, showed an increasing number of bacteria. On the third and fourth days after the first passage of bacteria through the porcelain wall of the cylinder, the number in each cubic centimeter varied above and below 400 000. The filter was then sterilized by steaming for five hours, as was also done between the second and third series of tests. These tests bore out the results of the former observation.

That these results show that average specimens of this substance have the inherent defect of all filtering material, though in a much less degree than all others, seems to me unquestionable. That the bacteria did not get through owing to some defect in the particular filters which I used, is evident from the fact that the cylinders employed (and which were selected by me in Paris as perfect), through which the bacteria passed, are still free from any appearance of a flaw which could explain the passage of these micro-organisms. The same filter which (first of those used in my tests) allowed bacteria to pass through, has repeatedly filtered water free from all bacteria for a few days, after each of the several sterilizations which it has since undergone.*

In three following series of trials of this identical cylinder, bacteria have gone through its walls in from three to four days after each sterilization. They have also gone through a second perfect cylinder with which I experimented. That the bacteria were not introduced by careless manipulation is evident by reason of their number, and because of the fact that, after the filter was sterilized, they were found in each case at a particular phase of each series of tests with the intermittent pressure, which only for a few hours once a week was as high as 18 pounds, and was usually as low as 11. At the beginning of each series of tests the filter was sterilized.

The bacteria were not splashed in from the sink below, for, in the first place, all splashing failed to carry in any, as revealed by testing the water filtered after such experimental attempts to throw water in, and none had ever multiplied inside or even remained there during my first thirteen tests, when there was much splashing in the common sink. During my later trials there was no chance of such contamination.

To answer fully in advance any such objection, I will state that after I got the enormous number of over 400 000 in each c.c. flowing through the porcelain, and had sterilized the cylinder, water was allowed to flow

* My results have later been corroborated by experiments made in Koch's laboratory, in Berlin. Kubler, *Zeitschrift für Hygiene*, viii, 48 (1890).

through it and plated, but was sterile in that no bacterial colonies developed. Then, while the filter was in action, I introduced, with a sterile needle, (from below through the aperture into the inside of the cylinder), and, touching the needle to various parts of the surface, deposited over it peculiar bacteria from a pure culture, derived in the winter of 1888–89 from the water of one of the northern lakes, which I examined during my investigations as biologist for the Syracuse Water Commission. The colonies of this bacillus, when grown on gelatine plates, have a peculiar odor, a distinctive green color, and other characteristics which clearly differentiate them from any bacteria ever found in the Croton water. The water flowing out all the while, or rather dropping out, was, three minutes after the introduction of these, collected in sterilized test tubes, and was found to contain 175 000 of these peculiar bacilli in each c.c. After seventy five minutes there were only 14 bacilli in each c.c. of the water then flowing through the porcelain, and two hours later, and during the next day, there were no bacteria of any kind in the water, which again later in the series showed that the Croton bacteria had passed through with it. This proves that the increase in the number of bacteria was not after the water had passed through the substance of the filter.

These facts, together with the extreme fragility of this rebaked porcelain, and the exasperating slowness of the flow, which does not improve on long trial, have caused me to modify the recommendations which I gave among my colleagues and others after my first tests of these filters.

As regards rapidity of flow and non-fragility, a notable improvement over the cylinder form (which I have just spoken of) is afforded by a series of two or more flat plates of porcelain similarly prepared. In the Varrall-Brisse pattern these porcelain plates are backed by carbon plates of the same shape and size, and the filter yields sterile water for a long time under gentle pressure, although I do not consider the carbon an advantage. The further such filters vary from the simplest type, the greater is the likelihood of the introduction of contaminating bacteria into the filtered water.

Of the various forms of filters used upon faucets, I feel bound to warn against those rotating within an outer shell. Whether packed with charcoal, sand or any other material, and even if the water go through the filtering mass and not around it, the filter has the great drawback of various irregularities and depressions on the interior which retain organic matter, and allow bacteria, both harmful and harmless, to increase in it, and maintain their vitality for a longer time than in ordinary filters. This conclusion I am led to by the results of various experiments and observations. In a recent epidemic in a large New England city this form of filter appeared to play an active part in continuing the infection, for cultures, in every respect like those of the germs of typhoid fever, were derived from several of these suspected filters. I have found that the typhoid bacillus lives much longer in the sediment collected from filters than in pure water. At its best, this filter cannot remove the bacteria from water, and they multiply in the charcoal or sand so that, even after several minutes of washing out by the stream flowing from the hydrant, the water coming through this filter may show several times as many as are in the water directly from the hydrant. To avoid waste of time in repetition, I will refer to the facts observed with the sand filter, as the mechanical action of the filtering mass is identical in both.

The sand filter, for attaching to faucets, is perhaps the simplest and

most popular used. It consists of a cylinder of like breadth and length, being not quite 3 inches long. It screws by either end upon ordinary faucets, and its interior is filled with crushed silica or fine sand, kept in place by wire gauze at either end. I have adapted several much larger without securing more satisfactory results. Taking a new one, sterilized throughout, allowing a fair stream of water to flow through it when attached to a faucet, and at the same time taking water directly from the same supply-pipe from the hydrant by means of another faucet by its side, and under the same conditions of pressure and outlet (except that there is no filter upon the second faucet), the water is seen to flow in a free stream nearly as large as from the unobstructed faucet, while the Pasteur filter attached to the same supply-pipe, and with the same pressure, allows the water to come at the rate of only a few drops each minute. Even with a gentle stream through the freshly sterilized sand filter, very few of the bacteria are arrested. With very fine sand in a cylinder holding three times as much as the ordinary one, and a very small stream flowing. I have observed more than 50 per cent. to be retained. This result is seen only in the first use of an absolutely sterilized filter.

Speaking of the tank variety of sand filters, it was shown that moistened sand favored the increase of bacteria brought into it by Croton water which had flowed through. In the sand or other granular contents of these filters attached to hydrants, the same multiplication takes place when the water has for some time ceased flowing, and this increase is at a more rapid rate than in water standing in a clean vessel by the side of the filter. The first flow in the morning, for instance, after the filter has remained unused over night, shows a much larger number of bacteria than the hydrant water then contains. Even after the water has flowed for several minutes for the purpose of washing out the filter, the bacteria are in excess over the number in the original water. After such a filter has had the hydrant stream running through it long enough to wash out all the germs that have resulted from the increase (which complete cleansing is not always producible), the bacteria in the water may appear nearly the same in number as in the hydrant water, varying slightly either above or below. While such filters are worse than useless from a bacteriological point of view, they are good strainers when not clogged by too long use without cleansing. As strainers they are less troublesome than flannel bags (which are as safe as these sand filters for use with suspected water, provided that they are removed at least once a day to be disinfected by boiling). The act of reversing this popular sand filter does not cause the removal of the organic matter upon which the bacteria can be nourished. Only the loose outer portion is thereby removed. Such a sand filter is a safer strainer when never reversible, and it should be cleansed at least once a day when needed at all.

Powdered magnesia and other granular substances used instead of sand in the style of filter just described, have no superiority over the easily cleansed sand.

Asbestos board I have not been able to procure of sufficiently firm, strong and fine surface to resist the passage of bacteria under any considerable pressure from the hydrant brought to bear upon such a surface. The quality of the surface seems the important point. To yield a flow of any degree of rapidity, this surface must be large, and that creates a tendency to break and necessitates a bulky filter, which most people shun. Packed asbestos shreds allow a few bacteria to pass through when the sterilized filtering mass is so dense as to cause the flow to be very slow. In this substance, I have, as already mentioned, not observed

so marked multiplication of bacteria as in the sand, porous and other filters.

Although large bodies of sand fail to prevent the passage of bacteria with the water which percolates through, it is noticed that certain natural filters of this sort render water much freer from bacteria when the water has first to make its way through a layer of silt, and minute particles which have been arrested by fine sand. It is from the application of this principle that the large filter-beds are built which purify the water distributed by hydrants throughout various cities. Taking as a model the very carefully managed filter-beds of Berlin, it is seen that above the base of the filtering tanks is a layer of a foot of stones, gradually becoming smaller in size toward the upper surface, upon which is coarse gravel to the height of a foot more, then upon this a little more than 2 feet of sand, which at the top is as fine as can be procured. Yet the engineer in charge has recently said that apart from its merit of keeping back the finest particles, the finest sand is not necessary. When the filter-bed has been freshly cleansed, as is found necessary for it after being constantly used for a week or so (occasionally several weeks), purified water is slowly backed into the filtering-mass from below, until this water, carrying up all the air with it, has reached the top of the upper layer. Then the ordinary river (or lake) water is made to flow very gently in, to the depth of 1 meter. This is allowed to stand for at least twenty-four hours. The nitrogenous or other particles, confervoid vegetation and whatever else the water contains as sediment, have, with many micro-organisms, then settled upon the upper portion of the fine sand without sinking deeper, and a delicate film is formed, which, with careful inlet and gentle pressure (never to exceed 2 meters of water), retains nearly all the bacteria of the water supplied, and prevents their passage, provided that the flow through is very regular and slow (never more than 3 meters in a day). With similar filters in Zurich it is found that perfect results are had when the flow is more than four times as fast. Nearly all this separation of the bacteria is produced by the sedimental matter retained on the surface of the sand, so that, when the filter slows from clogging, it is found that less than $\frac{1}{2}$ inch of the upper layer of sand need be removed.

While I have not seen as yet the unpublished report of the elaborate experiments made at Lawrence, on the Merrimac River, under the auspices of the Massachusetts Board of Health, I learn that they inculcate the importance of slow, intermittent filtration for purification of water having much organic matter. I learn on the best authority that these results seem to substantiate the familiar theory that nitrifying bacteria are the most important agent in producing this improvement. This, of course, is true as regards sewage poured upon soil.

On sand-filters as used to purify a bad water for city consumption, it seems to me undesirable to accept this theory as, *e. g.*, Drown does, to explain the great diminution which the best filters cause in the number of bacteria. He, in announcing these results, refers for authority to the presentation of this theory by the engineer of the Berlin water-works, Herr Piefke. The latter, however, when associated with an expert practical bacteriologist, as with Fraenkel in his last article on filtration (see *Zeitschrift für Hygiene*, viii, page 22 and following pages), allows most importance to be attached to the maintenance of the overlying film whose mechanical action is the main reliance. In the article by these two writers, it is asserted that if typhoid germs happen to pass through this film (either by proliferation or owing to a flow) the other bacteria cannot be depended upon to arrest these, even if the water flow slowly. They surmise that the considerable number of cases of typhoid in Berlin

during the early part of 1889, probably came from the use of water in which were the peculiar bacteria of this disease, and that these had passed through the filter.

The nitrifying bacteria are important in causing the purification of water, but we, as yet, do not fully understand them. That the felt-like film above the sand of such filters is by far the most important element, is further made probable by the report of Bertschinger (Zurich, 1889), who found that the waters passing through the Zurich sand-filter, became chemically and bacteriologically very pure; yet they flowed through at times faster than at the rate of 36 feet a day, which is very much faster than allowed by the postulates of those who claim that the nitrifying bacteria do most of the work. Still more emphatic are the excellent results where the various proprietary filtering arrangements force water very fast through sand in which, by *e. g.*, hydrate of alumina and silt, a tenacious filtering mass is produced. It is apparently necessary to study each filter-plant by itself, as the conditions of efficient operation seem to vary with the character of the water to be purified.

From the statistics of Wolffhügel, and of Plagge and Proskauer, we learn that the number of bacteria, originally very large in the river Spree, is reduced to a very small percentage in the filtered water, oftentimes a fraction of 1 per cent. I may add that the organic constituents are also decidedly lessened, and that the oxidibility, as tested by the reduction of a standard solution of permanganate of potash, is seen to be regularly lowered one-fourth, and often one-third of the amount shown prior to the filtering. The long arrays of figures given in the reports of the action of these filter-beds show, that with hardly an exception, the ammonia is constantly removed by the process.

In this country the filter-beds, all of which are built upon the same plan as those in Berlin, are less perfect in their action, as the people in charge do not devote sufficient care to sedimentation in the case of those which I am familiar with. Thus, a very carefully planned filter-bed, which filters river-water for one of our cities, allowed, at the time when I examined it, nearly half of the large number of bacteria in the water pumped from the river to pass through. This unsatisfactory result seemed to be due to the fact that too much water was required from the small filter-beds, and hence not enough care could be bestowed upon thoroughness of the filtration.

Of the various large filter systems which I have tested while they were in use in various manufactories and institutions, for which these filters were straining large quantities of water, the only kinds which reduced materially the number of bacteria as found in the hydrant water, were those in which by the addition of a minute proportion of a suitable salt, usually alum (as approved by the general experience of years in many districts), the suspended particles with the organic matter are caused to settle more rapidly, and then these form a deposit upon very fine sand, through which water is forced. From several examinations of a filter of this type, which in every case rendered the water much freer from germs than the original (unfiltered) water, I once found the filtered water wholly sterile, while the (Brooklyn) hydrant water of the neighborhood at the same time showed 397 germs developing from each cubic centimeter. This particular filter was constructed on the principle of Prof. A. R. Leeds, who informs me that the alum was present in the proportion of only 1 part in 100 000 of water. I could not, by the ordinary tests, detect the presence of this salt, and such a small amount can cause no appreciable harm. The alum used is probably decomposed, and its elements taken up by the organic matter and bases

present. As previously stated, the sterilization of the water is here caused, not by chemical but by mechanical action, which rapidly produces these excellent results without any recourse to assuming the activity of bacteria of "nitrifying" kinds. In my tests, the typhoid bacillus of the first agar culture from a recent spleen, was not destroyed by standing for forty-eight hours in a solution of ten times the strength of that employed in these filters, while many other bacteria were alive after standing for forty-eight hours in an alum solution of 1 part to 1 000 of water, which sufficed to destroy the typhoid bacillus in that time.

In the present stage of chemical knowledge, there seems no sufficient evidence that in water, these micro-organisms evolve the organic alkaloids which are considered to be produced when harmful bacteria are introduced into the system, and by their action there cause disease. What the exact nature of the volatile organic constituents carried over in distillation may be, and whether they are in any way deleterious or not, rests for the science of the future to determine. The process of boiling previous to vaporization in the still, must kill all harmful bacteria, and all other bacteria that I have ever encountered, in the original hydrant water from which such water is prepared. The bacteria which I have found in specimens of distilled water, must have been introduced from without after the water was condensed from the still, and before the bottling process was completed, but in this I have never found any other than harmless varieties. Water condensed from various stills of approved patterns I have found sterile. The relatively large amount of free ammonia found in such distilled waters (it being several times greater than any detected in the Croton hydrant water) does not seem to me to be objectionable. The condensed steam produced in distilling, represents a much larger original amount of water than results after the process of vaporization and condensation is completed, and the ammonia may besides come from the air and from other sources.

To those who desire a water freer from alkaline earths than the ordinary "hard" water which they may have to drink, it should be mentioned that the process of heating, in the sterilization by boiling which I so urgently recommend when it is necessary to drink suspected water, drives off free carbonic acid, and so causes the deposition as an insoluble sediment, of the carbonate of lime and other objectionable salts which form the so-called "temporary hardness." The water is thus rendered "softer."

When boiling is resorted to because of actual infection of the water, it should be carefully done. It is best to have the water, perhaps after a preliminary boiling and straining, decanted into bottles, each holding, say, a quart, and these covered with a suitable glass cap, or plugged with cotton, or provided with a clean stopper loosely dropped in, and then the bottles placed in a kettle or cauldron in the absence of a steaming apparatus. This is heated and kept near the boiling point for half an hour. Then the whole is allowed to cool, and the bottles may be placed near ice; but in the water thus carefully prepared it is not advisable to put ordinary ice, for harmful bacteria may retain their vitality in ice longer than in water. Pure water loses all its excellence when unwholesome ice is melted in it. For those to whom the taste of boiled water is unpleasant, weak teas, wine or other savor may be added to mask the absence of the more agreeable taste imparted by the process of aërification (which under ordinary conditions may itself be a means of adding bacteria to the water).

SUMMARY.—Boiling sterilizes water, and within less than five minutes will have killed harmful bacteria of any kind that are liable to occur in water.

Drugs and other agents acting chemically, if used in amounts which are commonly safe, do not sterilize water till after an impracticable lapse of time.

The prolonged heat which water undergoes in the usual process of distillation, destroys all germs which may be in the water undergoing the process.

Ordinary filters, even if satisfactory as strainers, fail to remove all bacteria from drinking-water. So far from lessening the number in the original water, the filtering substance may allow a more rapid multiplication than these micro-organisms would ordinarily undergo in the unfiltered water on standing; and the germs of disease, even if held back by the filtering substance, may be harbored in all filters.

The finer the substance through which the water passes, the lower the pressure and the slower the flow, the more perfect is the action of the filter in holding back the bacteria.

Of all substances thus far furnished for domestic filters, porous rebaked porcelain, carefully selected, I have found to be the best. If thick and strong enough to allow the use of a large surface, and the substance remain perfect (without flaw or break), this may yield a fair flow of clear water, free from all bacteria; yet under our ordinary Croton pressure of one atmosphere or less, this yield is only in rapid drops, unless the apparatus be complex.

To insure the permanency of this action, the filter should be occasionally sterilized throughout, by steaming or by other means; for under prolonged pressure, various kinds of bacteria can go through, and in the copious organic matter collected on the filter some harmful micro-organisms can retain a high degree of vitality for weeks longer than I have ever found them to live in pure water.

Where filtering is really necessary, it is generally best for the community that it be done carefully on a large scale through sand-beds upon which a fine layer of organic and inorganic matter is expressly produced by sedimentation, because of its valuable action in holding back the great majority of the bacteria.

A bad water, filtered, is less desirable than a pure water in its natural state. When, therefore, filtration is employed because of real danger of infection, the filtered water should, as a rule, be furthermore boiled, as the entire absence of sediment and cloudiness does not insure that the bacteria of disease may not have made their way through the filter.

DISCUSSION.

CHARLES B. BRUSH, Director Am. Soc. C. E.—Does the pressure in the pipe tend to reduce the vitality of the bacilli?

Dr. CURRIER.—Not necessarily; it may somewhat.

Mr. BRUSH.—Do muddy rivers and rivers carrying a large proportion of silt have a tendency to reduce the actual amount of life?

Dr. CURRIER.—That depends on the composition of the silt.

Mr. BRUSH.—When silt is removed by settlement from silt-bearing rivers like the Missouri, does this settlement remove the bacteria in water?

Dr. CURRIER.—Such settling may remove some. But sedimentation is most effective when caused by the artificial introduction of lime, as at St. Louis, or by alum, which is used in some large filters. An organic combination is thereby formed which carries down more particles than do settling particles of sand or other heavy particles.

Mr. WM. E. WORTHEN, Past President Am. Soc. C. E. said: Dr. Currier states, "The best deep springs show few or no bacteria; and uncontaminated water flowing directly thence is, unless highly impregnated with minerals, the most wholesome of beverages." It has been my experience that such well-waters develop algæ readily and abundantly when exposed to the air, as in all cold household springs these algæ invariably hang around the barrel, in the well-water supplies of Newton and Waltham, the water supply of Fort Wadsworth, Long Island City and East New York, which last were under my charge. Protecting the reservoirs and springs from air and light has, when tried, invariably stopped their development. The function of these algæ, as generally received, is to supply oxygen to the water in form of solution, and not mechanically. Although algæ are not generally considered dangerous to life, or detrimental to health, they are objectionable to consumers on account of the color given to the water in their life, and the taste and smell by their decease. It has been a question with me whether the water would not be better if the algæ were left to develop and absorb, whilst living, into some higher organisms. I have propounded this question to our member, F. P. Stearns, of the Massachusetts State Board of Health, with the following reply: "I suppose that ground water does contain less oxygen than surface water, although it will acquire it in a very short time on standing. I do not understand that it contains the undeveloped germs, but rather the food upon which the germs of algæ already in the reservoir thrive, and I think it may be a question whether horse sense is to be trusted. With regard to the death rates from a disease like typhoid fever, I believe that during the last eighteen years there have been 10 per cent. more deaths from typhoid fever at Lawrence than at Lowell, and more deaths at each of these places than at most large places in the State. There is one city, however, with an unpolluted water supply, which has had 50 per cent. more deaths from this cause; and the variations between other cities which have equally good water supplies are greater than between Lowell and Lawrence, showing that other causes have a greater effect than the water supply."

Time is a very large element in determining the value of facts and the inductions from them. Dr. Wolcott, in his address as President of the Public Health Association, says: "Unfortunately, man's life is hedged about with many injurious influences, which we do not understand accurately, and which we cannot remove.

"In several cities of Massachusetts, epidemics of scarlet fever, as well as of diphtheria, have been recorded, under conditions that can leave no doubt as to the accuracy of the observation, which have at some seasons shown a marked activity in well-drained and otherwise well-cared-for districts, and have had but limited development in other portions of the same city, where drainage is defective and crowding marked.

"The difficulties of interpreting vital statistics, for the purposes of the sanitarian, are by no means small. We have not been gathering them for periods of time sufficiently long, over territories sufficiently wide, to justify definite conclusions upon a large number of public health questions. Before the beginning of the Christian era, the bubonic plague was the one great epidemic of the middle ages. The pestilence raged with such fury that 100 000 persons perished in London in 1665. The retreat had already begun when London was burning, and Western Europe, by no effort of her own, was at last free from the most fatal epidemic of modern history. In the years from 1800 to 1804, scarlatina was prevalent in Ireland, and very fatal, while in the succeeding years, down to 1831, the disease had so far changed its character that physicians in large practice could say that they had never seen a fatal case. Therefore medical men were led to believe that this change was the result of better treatment. In 1831, however, an outbreak of scarlet fever took place which had all the characteristics and all the malignancy of the earlier epidemic."

I would also refer further to Dr. Wolcott's and Dr. George M. Sternberg's address as Presidents of the American Board of Public Health, as to the value of plate culture of organisms and of the sterilization of water.*

"With regard to the development of typhoid fever and cholera, the literature is very extensive, and hygienists have not yet arrived at any settled theory; they neither agree upon their facts or upon the causes. We believe with Dr. Currier that water becomes purified by flowing as a fact, and as a necessity that there must be some means provided by nature to destroy the excess of pathogenous microbes. If it is done by saprogenic microbes, or the bacteria of putrefaction, it might be well to increase the production of these last, and let higher organisms absorb the survivors—keep the aquarium balanced. In fact the pathogenic organisms must be very much in the minority, and subject to many destructive influences. It is doubtful how far certain pathogenic forms are specific causes of the disease in which they have been found in the tissue. The pneumo-coccus is announced as the germ of consumption, and yet there are microbes in the normal saliva of man which by injection produce the same results as the pneumo-coccus.

"Numerous bacteria exist in the digestive canal of a man in good health. Recent researches tend to show that these microbes are not only

* Troussart on "Useful Microbes."

innocuous, but that they play an active part in gastric digestion, and especially in the transmutation of albumens into peptones. Since they are, in fact, living ferments, the transmutation is retarded if these microbes are eliminated. It is therefore probable that they manufacture pepsin." Pasteur's experiments also tend to show that microbes aid the germination of plants. "If the microbes contained in vegetable mould are withdrawn from it, without taking away any constituent, germination is retarded and effected with difficulty." If they are withdrawn from the animal frame, may not the same effect be produced on generation.

We take into our system some half a million microbes per day, which, according to some medical authors, are the food of the phagocytes or leucocytes, on which the healthfulness of the blood depends. Whether it is so or not, in view of the immense numbers and diffusion of microbes, it is evident it will be impossible to try the experiment of complete sterilization.

The literature of microscopy is pleasant reading, but it should be supplemented by a comparison with death and disease rates, and by practical observations of what we can see directly with our eyes.

The office of Vital Statistics is the most important one in our Boards of Health; the officer in charge should be intelligent and active, results should be tabulated and published, and all the conditions should be noted bearing at all on the probable cause of the disease.

Prof. ALBERT R. LEEDS.—In attempting to discuss the extended paper of Dr. Currier, there is considerable difficulty, due to the many disputed points he has touched upon, and the necessity of often-repeated and most careful experiments requisite to arrive at anything like definite conclusions of practical value. In the first place, the views of Pettenkofer and the champions of the so-called "ground-water theory" of the causation of epidemics, are placed in comparison with the more recent "drinking-water theory," and the author presents no very definite conclusions as to the truth or falsity of either. I have supposed that it would reflect the views of the majority of those who have followed the long-continued controversy on this subject, to assign to the hypothesis of Pettenkofer and the Munich school a historical value mainly, while the great consensus of opinion is definitely in favor of the hypothesis which has been worked out by the more exact and more advanced experimental methods adopted by Pasteur, Koch and their host of followers.

The author states his belief that a water containing a large number of bacteria, especially if many varieties are detectable, is undesirable as a beverage so long as it has not undergone the sterilizing effect of heat. From the form in which this statement is put, it would seem that such a bacteria-rich water would be desirable as a beverage after it had undergone the sterilizing effect of heat, and I desire to learn whether this is the author's meaning.

Furthermore, in the case of any particular water, how many bacteria

and how many varieties should it contain before it would become undesirable before, and desirable as a beverage after, it had undergone heating. This is a practical question of immediate importance to the water-drinker. The Croton water, for example, frequently contains over four hundred colonies per cubic centimeter, and sometimes has over one thousand. The author found in the Delaware River, at Water Gap, three thousand four hundred colonies. This water, on the score of chemical purity, was recommended by the officers of the survey for the future supply of Philadelphia. And yet the number of bacteria is twice that reported by the author as present in the Passaic River, which, on the score of both common observation and chemical analysis, is one of the most polluted streams in this country.

Is it not true, as a matter of fact, that the one thousand colonies in the Croton water, the three thousand four hundred colonies in the Delaware water, weigh but little in the estimation of the bacteriologist if he feels sure on other grounds that the Croton water-shed, and the Upper Delaware water-shed, are demonstrably free from sources of serious sewage pollution?

I should be glad if the author would point out how the very few figures he has given, establish the fact of the self-purification of the streams examined. In the case of the Mississippi, the Passaic, the Delaware and the Schuylkill, there is an increase in the stated number of bacteria as we go down stream—how is this to be reconciled with the idea of self-purification. Also, if the author were to explain in what manner the old Croton Aqueduct affords opportunity for thorough aërification of the Croton water; which although dark throughout, and apparently different in many respects from ordinary flowing streams, is properly to be regarded as an ideal stream, and one admirably adapted for testing the question at issue.

In the same connection Dr. Currier calls attention to the fact of a slight epidemic of typhoid fever at Port Jervis, on the Upper Delaware, beginning October 1st, 1883; and apparently connects it with an outbreak of typhoid in Philadelphia, in January, 1884. Are we to understand his recommendation that the water should come to Philadelphia from a remote location through an aqueduct, to mean, that if so conveyed, the typhoid germs emanating from Port Jervis would have been destroyed; whereas with the apparently possible opportunities of self-purification afforded in so great a flowing river as the Delaware, they escaped destruction in the flow of more than a hundred miles.

It is important to bear in mind that the results of bacteriological examinations vary enormously, when they are made at different times and under different conditions. As an illustration I would quote the condition of the Passaic River during the summer and autumn of 1887. Those who are interested will find in the reports to the Newark and Jersey City Aqueduct Boards from 1881 and 1886 the chemical evidence,

on which I was led to infer that the large amount of sewage introduced at Paterson was oxidized at such a rate, that in case no further sewage were introduced lower down, the Passaic would have returned to the same condition as above the Great Falls during a flow of 16 miles. The reasoning is based upon the fact that while the dissolved inorganic substances go on steadily increasing in amount, the dissolved organic compounds exhibit a progressive diminution. A similar fact was noted in the condition of the Hudson River after receiving the sewage of Troy, and is stated in the reports to the Albany Special Water Commission. Also in the reports of the Philadelphia Water Department, as true of the improvement in the character of the Schuylkill River water, in its flow of 7 miles below the influx of the sewage from the town of Manayunk. In the case of the Hudson River, a corresponding series of biological analyses was made of the waters below Troy; and while the biological analyses did not correspond exactly with the chemical, the decrease in the number of bacteria as a general rule, corresponds with the oxidation of the dissolved sewage contamination.

Besides the evidence contained in the reports above alluded to, showing the dangerous pollution of the Passaic River, there is a further report, made at the desire of my colleagues of the State Board of Health in the year 1887, in which are given the results of a combined chemical and biological examination. In that report the condition of the Pequannock River above Butler is taken for comparison, and its great chemical purity is shown, with the corresponding low number of bacteria, of 70 colonies per cubic centimeter. The monthly analyses of the Hackensack River during the past 5 years having shown that with the exception of its somewhat high percentage of peaty matters, it was otherwise pure, this was examined and it was found to contain at the time of the investigation 200 colonies per cubic centimeter. But the Passaic, above the Great Falls, contained 4 000 colonies, while below, after receiving the Paterson sewage, they were innumerable. One mile below Paterson there were 72 000 colonies; and two miles below, 64 800. These enormous numbers are evidence certainly of great pollution, and at the same time of an apparent progressive improvement going down stream.

But other tests made lower down did not show such a progressive improvement, nor can I well see how this was to be anticipated, considering the variable increments of sewage coming in at the city of Passaic, the second river, the third river; and what is carried up stream even beyond the Newark and Jersey City intakes by the tidal flow, carrying with it the sewage emptying into the Passaic from the city of Newark. So that while thirty determinations of the number of bacteria at different points were made, they appeared insufficient to generalize from. I shall simply note here, as a point less studied perhaps by other observers, that the Passaic River below Paterson,

where the colonies of bacteria were so numerous as to defy counting, contained in solution but 2.97 cubic centimeters of oxygen per liter, while above the Great Falls it had 6.57 cubic centimeters. The Pequannock exhibited nearly the point of saturation with oxygen, or 7.22 cubic centimeters. So far as the evidence at present in our possession is concerned, it appears to show that with the incursion of sewage into a stream, whether from sewage or drainage, its content of dissolved organic nitrogen rises, and at the same time the number and variety of bacteria, while the percentage of dissolved oxygen sinks; and that when this sewage is submitted to the action of the various nitrifying and other bacterial ferments in a flowing stream, its organic nitrogen is oxidized, and the sewage is progressively destroyed. The evidence would appear to show that the multiplication of bacteria first takes place; then afterwards, along with the destruction of sewage, their progressive diminution. Such appeared a fair construction to put upon the results of the examination of the water of the Hudson River after receiving the sewage of Troy, of the Schuylkill water after receiving the sewage of Manayunk, and of the Passaic after receiving the sewage of Paterson. But a vastly greater number of analyses and determinations are needed, to speak with certainty upon these points. Similarly the number of bacteria in the Croton water varies between very wide limits. It may fall much below a hundred, and again it may rise, after a fall of rain or an increase of temperature, above a thousand. But except for the reason that the sanitary cordon around the streams on the Croton water-shed is not as yet rendered perfect, I don't think any one would seriously suspect that, even with 1 000 bacteria per cubic centimeter, the Croton water is necessarily dangerous to drink. And such is the character of these variations, that while the figures given by Dr. Currier show a diminution along the course of the Croton Aqueduct, an eminent bacteriologist, especially familiar with the Croton water, stated to me that at times these figures would be reversed.

RUDOLPH HERING, M. Am. Soc. C. E.—The subject of Dr. Currier's paper is certainly one which is of great importance to those engineers whose business it is to arrange for water supplies and disposal of sewage. I was in hopes, inasmuch as there is still a great deal of darkness on the subject, that Dr. Currier would give us a large amount of additional light which would help us in our work. But, while I think his paper is a very able exposition of much of the matter known at the present time, I was disappointed to see that little had been done lately which could be of much assistance to us.

Regarding his statement of the different theories held in Europe and America as to the relation which the height of ground water holds to the prevalence of certain diseases, I recall an interview I had some years ago with Dr. Pettenkoffer on this subject, when I was surprised to see the strong evidence which had been collected. The tables he showed me

were certainly remarkable, as demonstrating the relation of the mortality of typhoid to the ground-water level in Munich. Later I saw similar tables for Berlin and other cities of Germany, all of which showed that when the mortality was high the ground water was low, and vice versa. I thought at the time, and this idea seems to be held by a good many, that the explanation of this peculiarity might be as follows: the time when the ground water is low and the death rate is highest, corresponds with the time when the streams are low. The pollution derived from the soil, from manure and decaying vegetable matter, is then relatively greatest; and during long dry spells there is also a great deal of dust in the air, which settles upon the water more than at other times. But the "drinking-water theory" is also supported by strong evidence, as, for instance, by the epidemics at Plymouth, Pa., and many other places. Yet we have cases which are authentic, showing that typhoid fever could not have been transmitted by drinking-water. It therefore seems as though neither theory were quite satisfactory, but that the modern assumption, that the bacteria or their products are the real cause of the disease, may reconcile both of the older ideas.

Chemistry alone does not seem sufficient to determine the presence of these bacteria, as I am informed that there may be 500 000 in a cubic centimeter without being discovered through any chemical means. I was in hopes to hear something about the typhoid bacillus, which seems to be especially important. The Massachusetts State Board of Health is about to experiment with this bacillus, and to ascertain, if possible, its life and behavior in soils and water. This board is doing some excellent work, which will undoubtedly help the engineering profession very much. I do not think that anywhere in the world there is such a fund of facts relating to the purification of water as this board has collected.

In enumerating the various causes for the disappearance of organic pollution in water, Dr. Currier mentions deposition, by which bacteria tend to settle. He also mentions a number of instances which show that oxidation and the development of bacterial life is restricted by light. The English Rivers Pollution Commission, through the works of Dr. Frankland, who was in charge, seemed to show quite the contrary, namely, that light rather invited oxidation. They say that such oxidation is more active in sunshine than in shade, and is almost entirely arrested at night, or when the thermometer approaches the freezing point, showing that oxidation depends on the same conditions as those favorable to the life of low organisms. It may be, however, that more recent investigations have shown that these assertions need qualification.

Regarding large filters, Dr. Currier says that when they are carefully managed they effect great improvement in inferior waters. It is precisely on this subject that the Massachusetts State Board of Health has reached some definite and more or less new results. They have erected ten large filter-beds, consisting of tanks, each 16 feet in diameter, and

filled with different kinds of material, such as coarse sand, fine sand, loam, garden soil and peat. They have experimented not only with the water from the city supply, but also with sewage. The results obtained differ in some respects from what has formerly been supposed to be true. For instance, it has been found that peat, which is mentioned in different works as being a good material with which to purify sewage, is not at all capable of purifying it for any length of time. The board find that the purification of water depends on the physical condition of the material through which it filters, on the fineness of its grains, on its porosity, on the continuity of the pores which permit the air to follow the water or sewage when it is intermittently applied, and upon the presence of bacteria which effect the nitrification of the organic matter.

In experimenting with different kinds of soil, different degrees of porosity, etc., the board find that the best material for purifying sewage is sand of the fineness of common mortar sand. That the purification is not a straining process, they have proved by pouring sewage upon coarse gravel stones, 5 feet deep, from which all sand had been washed. When applied intermittently, a little at a time, at the rate of 80 000 gallons per acre daily, "each stone was kept covered with a thin film of liquid, very slowly moving from stone to stone and continually in contact with air in the spaces between the stones. The liquid, starting at the top as sewage, reached the bottom within twenty-four hours with the organic matter nearly all burned out."*

The board has further found that a certain time elapses before the nitrification sets in, and that by a persistent application of water or sewage the capacity of a given filter can be increased. It has been found that "a bed of coarse mortar sand, having particles about $\frac{5}{100}$ of an inch in diameter, there can be filtered intermittently for an indefinite period —*i. e.*, year after year—from 50 000 to 100 000 gallons of ordinary city sewage upon an acre, daily, without any accumulation of filth in the sand after the first year, and giving a bright, clear, colorless water, which chemical and biological analysis show to compare favorably with water from some of the wells used for drinking in some of the thickly settled parts of towns and cities in this State"* (Massachusetts). With finer sand, having grains which were but $\frac{5}{1000}$ of an inch in diameter, there could be filtered daily from 15 000 to 30 000 gallons per acre with a complete removal of all bacteria, and with a purity greater than that of most of the drinking-water supplies of the State.

The water used in Lawrence for domestic purposes when filtered through fine sand, could be applied at the rate of 3 000 000 gallons per acre, and thereby be rendered pure.

While the principles of purification through sand are not directly applicable to the purification of polluted water in streams, yet they may give us a clew by which we may also determine under what conditions

* "Lend a Hand," September, 1890.

we can best purify foul waters when mingled with the comparatively pure waters of running streams; for that reason I thought it might be of interest to mention the results which have been reached in Massachusetts.

The CHAIR.—Are these results contained in the last reports of the board?

Mr. HERING.—Some of them are, and others appeared in print in a short paper, published not long ago, written by Mr. Mills, who conducted the experiments.

Mr. WORTHEN.—The results, as I understand, will be published in full in the report of January.

Mr. HERING—I would like to ask Dr. Currier whether he took account of the question of dilution when he gave the number of bacteria in a cubic centimeter of water; many of these results seem to prove the reverse of what he wishes to prove regarding the self-purification of streams. In the case of the Kaaterskill brook, if I remember rightly, he gives 54 bacteria per cubic centimeter, and 1½ miles below that point he gives 49. Now, if in that 1½ miles this brook increased its flow 10 per cent., it would show that the same number of bacteria were contained in the cross-section, and that, therefore, there was no diminution in the number of bacteria. Again, in the case of the lake in the Rocky Mountains, he says there were 154 bacteria per cubic centimeter in the stream leading to it, and in the lake, which is quite large, he finds 43 bacteria in a cubic centimeter. It therefore seems that in going down stream, the total number of bacteria in the water is increased. But in many cases no doubt the reverse is to be found.

Dr. CURRIER.—Mr. Hering speaks of my wishing to prove a certain point; I merely show the result of a perfectly impartial investigation; the paper is simply a presentation of facts as I found them.

It must appear unsafe to consider that a river sufficiently purifies itself within a short distance from the entrance into it of a considerable amount of sewage or other contamination.

The slow filtration, which proved so satisfactory in certain of the Massachusetts experiments, produces very much purer water than is obtained when a large volume of bad water is rapidly passed through the usual large sand filter.

J. J. R. CROES, M. Am. Soc. C. E.—That the drinking of water may produce or aggravate disease in the human body, has been conceded by physicians for a great many years. The exact conditions of water under which injurious effects may be produced, have been the subject of investigation by a number of different classes of observers. Up to a very recent period the chemical composition of the water was the only subject of investigation, and disease was supposed to be dependent on the chemical action of certain constituents in the water on the tissues of

the body. About fifteen years ago it became evident, as the result of progress in microscopical and chemical investigation, that the forms of animal and vegetable life which are to be found in waters generally only by microscopical examination, produced, by both their growth and decay, certain effects upon the human system, without, at the same time causing any very material change in the chemical constituents of the water.

The vegetable organisms are classified as algæ, and have been discussed at some length in papers heretofore presented to the Society. There are also found in water, however, great numbers of what is now considered to be the lowest form of animal life, the organisms classified under the general head of bacteria, which are visible only under a microscope of high power, being generally less than the one-five thousandth part of an inch in length. These small creatures possess, however, a decided individuality, and are found to be divided into numerous families, each differing from the other in shape, size and color.

The careful investigation of Dr. Koch and other scientists appears to have established the fact, that certain species of these infinitesimal creatures are found in considerable quantities in the human body, only where certain diseases are known to exist, and the presumption is, therefore, that such diseases are produced by these species. These bacteria are found in water, and it may safely be assumed that where a water contains a large number of such species as are known to exist in certain tissues of the human body, only when these tissues are known to be diseased, such water cannot safely be taken into the human system. The reason for the appearance, growth and disappearance of these organisms in waters has not been accurately determined; but that injurious species do appear in running streams, and that the number of them increases or diminishes as the case may be, is well established. The object of the investigations, the results of which are embodied in Dr. Currier's paper, has been to discover more particularly whether in a running stream, in which at some point on its course an excessive number of these injurious bacteria have been discovered, there will be an increase or a diminution of such organisms in the course of the natural flowing of the stream through a channel, in which no apparent exciting cause for their generation or growth has occurred.

The method of investigation of these organisms is as follows: A preparation of ten parts of strong beef tea and one part of gelatine is submitted to steam heat long enough to kill any bacteria which may be in it, for it has been found that these small creatures cannot stand boiling. This mixture solidifies in cooling. While the gelatine is soft (at a temperature a little above 73 degrees Fahr.), 1 cubic centimeter or about a quarter of a teaspoonful, of the water to be examined, is added to the gelatine drop by drop, and the bacteria in the water are diffused throughout the gelatine by rotation of the containing tube. The mass is poured into a shallow glass dish and carefully protected from the con-

tamination of the air, and allowed to solidify. On examination with a microscope a few days later, the individual bacteria in the water which has been added are found to have increased and multiplied to an enormous extent, each individual being now the center of a mass of many thousands, and even millions, of individuals. These masses, called colonies, are visible to the naked eye, and their appearance differs greatly. The number of the colonies is counted, and this number affords some criterion of the quality of the water.

To know whether the individuals composing these colonies are injurious or not, reference must be had to the investigations made by the scientific observers of bacteria. Many of them are supposed to be perfectly harmless, while others are pretty well proven to be disease-producing. The character is discovered by finding out what food they thrive on best, and what forms they assume in generation and growth. For this purpose various "culture media" are prepared, which are concentrated extracts of various nutritious substances, stiffened with gelatine or similar substances, and put in test tubes. A fine platinum wire, having been first passed through flame to kill any germs which may be on it, is touched to a "colony" and then plunged into a tube containing a "culture medium." The bacteria thus transplanted generate in a few days; and their growth and form can be studied under the microscope, and their class determined from their form and their rate of growth in that "culture medium."

Now, by taking samples of water in a stream at any point, and taking other samples of, as nearly as may be procured, the same water at another point lower down on the stream and treating both samples alike, it is possible to determine both whether the bacteria have increased or diminished in number, and whether such change of number has been greatest in the injurious or the harmless species. In general, if the number has greatly diminished, it may be assumed that the quality of the water has improved, for the harmless varieties are the more hardy, and appear moreover to destroy the injurious ones when they are brought into conjunction with them, without the addition of fresh supplies of bacteria from foreign sources.

GEORGE W. RAFTER, M. Am. Soc. C. E.—Dr. Currier's paper discusses one phase of the question of self-purification of water in flowing streams. There are, however, other phases of considerable importance, and the following, without exhausting the subject, may be taken as a partial view of some of the causes operating to produce such self-purification.

Among the invertebrata there are certain classes of microscopic animals which, under favorable conditions of sufficiency of food supply, multiply in enormous numbers. As common representatives of these minute animals, we may mention: (1) certain of the filth infusorians, as for instance *Paramecium;* (2) *Hydra*, as the typical representative of

the order Hydroida; (3) certain of the Rotifera, of which *Lacinularia* and *Conochilus* may be cited as perhaps typical forms; (4) the numerous species of animals included in the entomostracan crustacea; (5) *Gammarus*, or the fresh-water shrimp; and (6) the larvæ of a number of water insects.

In comparison with bacteria the infusoria are creatures of vast size, even though some species are as small as $\frac{1}{1000}$ inch in length. *Paramecium aurelia*, a form found I believe almost invariably wherever putrefaction of animal matter is taking place in water, is an infusorial giant, mature individuals measuring as much as $\frac{1}{96}$ inch in length. *Paramecium bursaria*, however, is much smaller, about $\frac{1}{280}$ inch being the usual length.

In addition to *Paramecium*, there are a number of other ciliate infusorians, which are almost invariably found in water containing organic matter undergoing decay, and examinations made by the recently developed methods of biological enumeration, indicate that from twenty to fifty such forms may be found in every cubic c.c. of badly contaminated water; but whether any such numbers would be found in running streams, even though flowing slowly, I have had as yet no means of determining.

Any notice of the infusoria in relation to the self-purification of contaminated waters, would be incomplete without some reference to *Euglena* and the allied genera. In standing waters *Euglena viridis*, an infusoria of bright green color, is frequently present in such quantity as to impart a green color to the water. Its length varies from $\frac{1}{140}$ inch to $\frac{1}{60}$ inch. The vast quantities of *Euglena* which are met with under favorable conditions are sufficiently accounted for when we learn that it may multiply, not only by fission, or by the division of one individual into two, but it further multiplies by the "subdivision of the entire body substance into sporular elements, and by the development of independent germinal bodies out of the substance of the endoplast."*

Euglena is generally found in quantity in streams contaminated with sewage. *Hydra* is an animal of considerable size, frequently reaching a length, when fully extended, of nearly an inch. It is attached to water plants in quantity in stagnant waters, and voraciously devours everything coming within its reach.

Rotifers frequently develop in vast quantity in waters carrying large amounts of organic matter; and among such *Lacinularia socialis* may be taken as typical. This creature is usually attached to water plants along the margins of slowly running streams; and in favorite locations at certain seasons, many hundred thousand colonies will be found in a limited space. The colonies are about $\frac{1}{3}$ inch in diameter, and frequently contain from fifty to one hundred individuals, each about $\frac{1}{12}$ inch in length. A single sprig of water plant has been found to support nearly one hundred colonies.

* Kent, "Manual of the Infusoria," page 379.

Another rotifer which may be mentioned is *Conochilus volvox*—a free-swimming, social form—with the colonies containing from seventy to one hundred individuals. The colonies are on an average $\frac{1}{20}$ inch in diameter, with the single members $\frac{1}{10}$ inch in length.

Probably the Entomostraca are of the animal forms the most efficient assistants in the self-purification of running streams. The vast numbers in which they develop, and the readiness with which they devour all sorts of filth, render them worthy of more extended study, from an economic point of view, than they have yet received.

As illustrating the forms especially worthy of attention, in this connection, may be mentioned *Daphnia*, *Ceriodaphnia*, *Cypris*, *Cyclops* and others. These are all found in waters containing decaying organic matters, and if the water is intended for domestic use, their presence in quantity may be taken as danger signals.* On the other hand, their presence in quantity may be taken to indicate a step in the process of self-purification of contaminated waters. As many as one thousand four hundred *Ceriodaphnias* have been counted in a single quart of such water,† and this number by no means exhausted the visible life in the sample.

A study of the Entomostraca, and observations of their immense fecundity and tendency to act as scavengers, led at an early day to singularly correct views as to the causation and spread of disease. Thus Otho Fredericus Müller, in his work on the Entomostraca, published in 1785, says: "The time is at hand when the causes of disease shall not only be sought after in the air, in our method of living, etc., but in the incautious use of waters often abounding in innumerable animalcules." The fertility of these little animals has already been referred to, and by way of illustrating it, reference may be made to Jurine's computation, that a single female *Cyclops quadricornis* might in one year have a progeny amounting to four billion, four hundred million.‡ The following are the average lengths of some of the animals of this group: *Daphnia*, $\frac{1}{10}$ inch; *Simocephalus*, $\frac{1}{8}$ inch; *Cyclops*, $\frac{1}{10}$ inch; and *Cypris*, $\frac{1}{25}$ inch. *Gammarus*, another crustacean of the order Amphipoda, is a denizen of sluggish-flowing, contaminated streams, where it may be frequently found in great quantity. This animal, when full grown, attains a length of $\frac{1}{2}$ inch. The larvæ of a number of insects pass their larval stage immersed in water, and among such the larva of the mosquito may easily take a high rank for large numbers.

The foregoing exhibits, in a very incomplete way, a few of the animals which assist in the self-purification of a running stream. The number of species which actually assist in such work is very great, and a mere enumeration of them would require considerable space. As to the

* Herrick, "Crustacea of Minnesota."

† Herrick, *loc. cit.*

‡ Baird's "British Entomostraca," page 190.

definite part played by each species little can be said, as, with the exception of the Entomostraca, none of them have been studied in reference to their economic value in this direction. The exception noted in the case of the Entomostraca is a partial study made by Dr. H. C. Sorby, of England, a few years ago.

Enough can be gathered, even though we possess little definite knowledge, to justify saying that animals of the classes under consideration play a very important part in the so-called self-purification of streams. Minute plants may also be considered as assisting greatly in such work, but this part of the subject I leave untouched at this time.

The question of self-purification may, however, be somewhat simplified, if we consider just the distinction which marks the division line between animals and plants. The specific difference may be readily appreciated, by considering that animals always require organized food; they seek those substances in which hydrogen, nitrogen, carbon, sulphur, etc., have been already assimilated into living forms, such living forms themselves being either animal or plant. Plants, on the other hand, have no power of assimilating organized food; they require rather the elements hydrogen, nitrogen, carbon, etc., in their primal state. In a general way, it may be said that this distinction holds good through the whole scale from the highest to the lowest. Indeed, when we come to deciding a difficult case, as for instance whether a given form belongs to the Protophyta or the Protozoa, we take advantage of this distinction, and the natural line of study is to determine in which way food is taken by the unknown form.

A proper appreciation of this distinction will assist greatly in understanding the phenomena exhibited by streams in the process of self-purification. Thus we seem justified in concluding, that if contaminating organic matter in streams is to be reduced to an innocuous form, without the intervention of foul, odor-producing, putrefactive processes, it will be accomplished, in the earliest stages at any rate, by the assistance of animals rather than plants. Just how animals and plants assist in the process of self-purification, is finely exhibited by the paper of Dr. H. C. Sorby herewith appended, entitled, Detection of Sewage Contamination by the Use of the Microscope, and on the Purifying Action of Minute Animals and Plants. Dr. Sorby says:

By studying with the microscope the solid matters deposited from the waters of a river, the previous contamination with sewage can usually be detected without any considerable difficulty. If the amount be serious, the characteristic particles of human excrement can easily be seen; and if it is small and has been carried a long way by the current, it can usually be recognized by means of the hairs of oats derived mainly from the droppings of horses, which resist decomposition for a long time, and are not consumed as food by minute animals. I, however, do not propose to enter into detail in connection with this part of my subject, but specially desire to call attention to the connection between the number of minute animals and plants and the character of

the water in which they live, and also to their influence in removing organic impurities.

For some time past I have been carefully ascertaining the number per gallon of different samples of river and sea water, of the various small animals which are large enough not to pass through a sieve, the meshes of which are about $\frac{1}{100}$ part of an inch in diameter. The amount of water used varies from ten gallons downwards, according to the number present. By the arrangements used there is no important difficulty in carrying out the whole method in a satisfactory manner. I confine my remarks entirely to general mean results. The chief animals met with in fresh water are various Entomostraca, Rotifera and the worm-like larvæ of insects. I find that the number per gallon and percentage relationships of these mark, in a most clear manner, changed conditions in the water, the discharge of a certain amount of sewage being indicated by an increase in the total number per gallon, or by an alteration in the relative numbers of the different kinds, or by both. All my remarks apply to the warm part of the year, and not to winter.

It is known that Entomostraca will eat dead animal matter, though probably not entirely dependent on it. I have myself proved that they may be kept alive for many months by feeding them on human excrement, though they soon died without it. If the amount of food in any water is small, not many of such animals can obtain sufficient; but if it be abundant, they may multiply rapidly, since it is asserted that in one season a single female Cyclops may give rise to no less than four thousand millions of young. In stagnant muddy ponds, where food abounds, I have found an average of 200 per gallon. In the case of fairly pure rivers the total number of free-swimming animals is not more than 1 per gallon. I found, however, that where what may be called sewage was discharged into such water, the number per gallon rose to 27, and the percentage relationships between the different groups of Entomostraca were greatly changed. In the Thames at Crossness, at low water, the number was about 6 per gallon, which fell to 3 or 4 at Erith, and was reduced to less than 1 at Greenhithe.

There is, however, a very decided limit to the increase of Entomostraca when the water of a river is rendered very impure by the discharge of too much sewage, probably because oxygen is deficient, and free sulphide of hydrogen present. Such water is often characterized by the great number of worm-like larvæ of insects. Thus, in the Don below Sheffield in summer, I found the number of Entomostraca per gallon only about one-third of what it is in pure waters; whilst on the contrary, the number of worm-like larvæ were more than 1 per gallon.

Now, if the minute free-swimming animals thus increase when a certain amount of sewage supplies them with ample food, it is quite obvious that they must have a most important influence in removing objectionable impurities. The number of excrements of Entomostraca in the recent mud of such rivers as the Thames is most surprising. In one specimen from Hammersmith, I found that there were more than 20 000 per grain; and the average number at Erith in August, 1882, was about 7 000, which is equivalent to about 200 000 per gallon of water at half ebb, from the surface to the bottom. This enormous number must represent a very large amount of sewage material consumed as food; and though, as in the case of larger animals, a considerable part of their excrements no doubt consists of organic matter capable of putrefaction, yet there can be no less doubt that the amount entirely consumed in the life-processes of these animals is also great.

As named above, I kept Cyclops alive for many months by feeding

them on human excrement. It is thus easy to understand why, when they abound in the Thames, the relative amount of human excrement is very considerably less than in the winter, when their number must be much smaller. We thus appear to be led to the conclusion that when the amount of sewage discharged into a river is not too great, it furnishes food for a vast number of animals, which perform a most important part in removing it. On the contrary, if the discharge be too great, it may be injurious to them, and this process of purification may cease. Possibly this explains why in certain cases a river which is usually unobjectionable may occasionally become offensive. It also seems to make it clear that the discharge of rather too much sewage may produce relatively very great and objectionable results.

Though such comparatively large animals as Entomostraca may remove much putrefiable matter from a river, we cannot suppose that, except incidentally, they remove such very minute objects as disease-germs; but it would be a subject well worthy of investigation to ascertain whether the more minute infusoria can, and do, consume such germs as a portion of their food. If so, we should be able to understand how living bodies, which could resist any purely chemical action likely to be met with in a river, could be destroyed by the digestive process of minute animals. Hitherto, I have had no opportunity for examining this question critically, but have been able to learn certain facts, which at all events show that it is well worthy of further examination. It is only during the last month that I have paid special attention to the number of larger infusoria and various other animals of similar type met with in the waters of rivers and the sea, which can be seen and be counted by means of a low magnifying power. At low water in the Medway above Chatham, in the first half of June, the average number per gallon has been about 7 000, but sometimes as many as 16 000. Their average size was about $\frac{1}{1000}$ inch. Possibly the number of still more minute forms may be equally great; but if we confine our attention to those observed, we cannot but conclude that their effect in removing organic matter must be very considerable. Judging from what occurs in the case of larger animals, those $\frac{1}{1000}$ of an inch in diameter may well be supposed to consume as food particles of the size of germs. Up to the present time, I have however collected so few facts bearing on this question, that it must be regarded as a suggestion for future inquiry.

So far I have referred exclusively to the effect of animal life. Minute plants play an important part in another way. The number per gallon of suspended diatoms, desmids and confervoid algæ is in some cases most astonishing, and they must often produce more effect than the larger plants. As far as I have been able to ascertain, their number is to some extent related to the amount of material in the water suitable for their assimilation and growth. In the mud deposited from pure rivers their number is relatively small, but in the district of the Thames, where the sewage is discharged, I found that in summer their number per grain of mud at half-ebb tide was about 400 000, which is equivalent to about 5 000 000 per gallon of water. This is two or three times as many as were found higher up or lower down the river, and out of all proportion more than in the case of fairly pure rivers like the Medway. Their effect in oxygenating the water must be very important, since when exposed to the light, they decompose carbonic acid and give off oxygen, under circumstances most favorable for supplying the needs of animal life, and counteract the putrefactive decomposition so soon set up by minute fungi when oxygen is absent.

Taking all the above facts into consideration, it appears to me that

the removal of impurities from rivers is more of a biological than a chemical question; and that in all discussions of the subject, it is most important to consider the action of minute animals and plants, which may be looked upon as being indirectly most powerful chemical agents.

[Excerpted from the Journal of the Royal Microscopical Society, 1884, pp. 988-991.]

A number of photographs of the animal forms referred to in this discussion were submitted, from which Plates Nos. VI to IX have been prepared.

DESCRIPTION OF PLATES.

PLATE VI.

An instantaneous photograph ($\frac{2.0}{1}$) of a living colony of *Lacinularia socialis*.

PLATE VII.

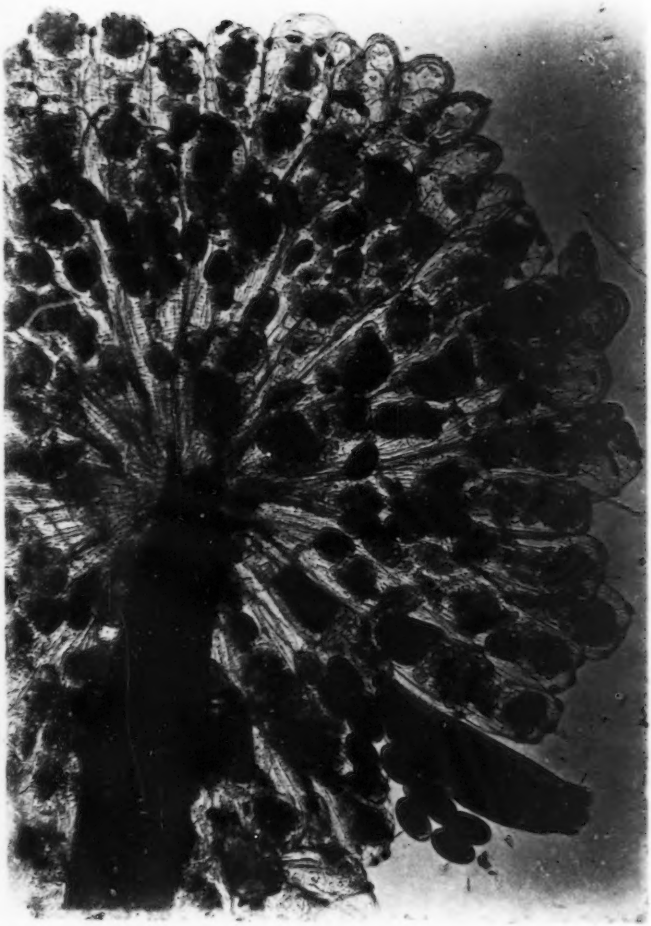
A mature female *Daphnia pulex* ($\frac{2.0}{1}$) with eggs.

PLATE VIII.

Fig. 1, $\frac{8}{1}$. Mature *Gammarus*.
Fig. 2, $\frac{2.0}{1}$. Female *Cyclops* with egg sacs.
Fig. 3, $\frac{2.4}{1}$. *Cypris*.

PLATE IX.

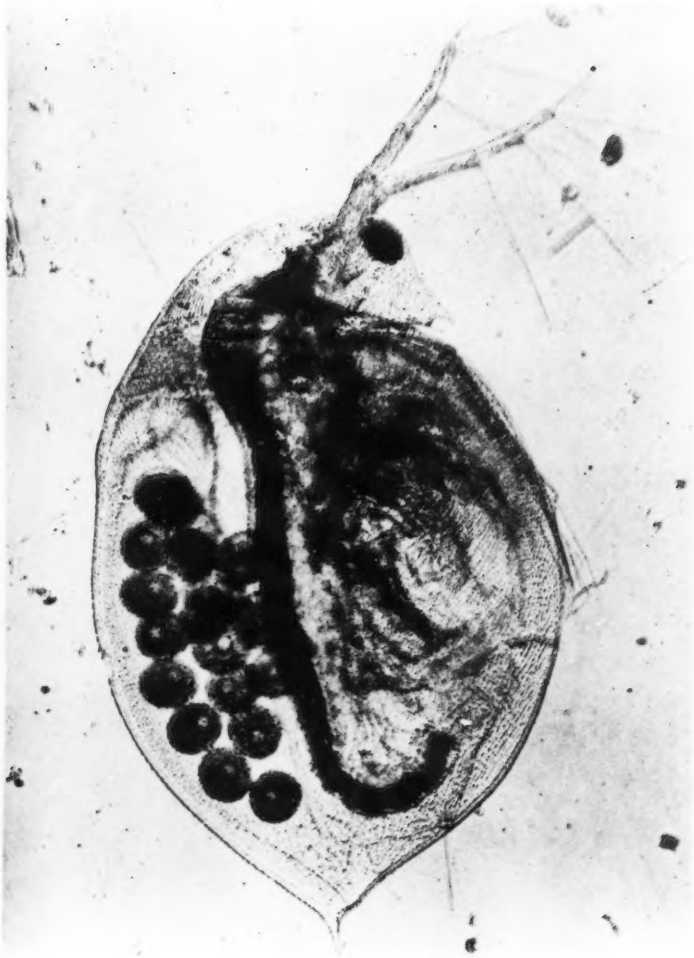
Fig. 1, $\frac{2.0}{1}$. *Sida crystallina*.
Fig. 2, $\frac{2.0}{1}$. *Chydorus*.
Fig. 3, $\frac{2.1}{1}$. Female *Simocephalus* carrying eggs.



$\frac{20}{1}$

Photo-Micrograph by
Dr. J. EDW. LINE.

Transactions of the
AMERICAN SOCIETY OF CIVIL ENGINEERS.
Vol. XXIV, No. 2.
Rafter on the
Self Purification of
Streams.



$\frac{30}{1}$

Photo-Micrograph by
GEO. W. RAFTER.

Transactions of the
AMERICAN SOCIETY OF CIVIL ENGINEERS.
Vol. XXIV, No. 2
Rafter on the
Self Purification of
Streams.

Fig. 1. $\frac{8}{1}$

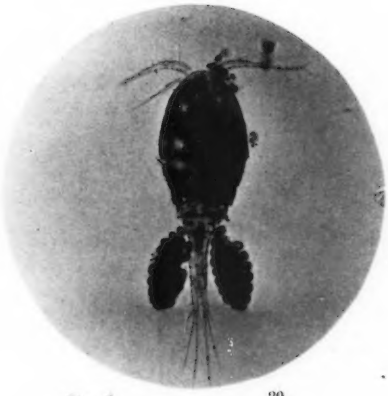


Fig. 2. $\frac{20}{1}$

Fig. 3. $\frac{34}{1}$

Photo-Micrograph by
GEO. W. RAFTER.

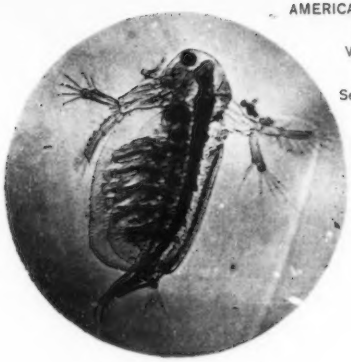


Fig. 1. $\frac{30}{1}$

Fig. 2. $\frac{30}{1}$

Fig. 3. $\frac{21}{1}$

Photo-Micrograph by
GEO. W. RAFTER.

S. WHINERY, M. Am. Soc. C. E.—It seems well enough established that polluted river-water tends to become purified when subjected to the influences brought about by the flow of the water, such as agitation, aërification and time; but the exact conditions under which this purification takes place seem not at all well understood.

We have a mass of testimony, collected by different observers, upon different rivers, which seems to show that in some cases very impure water becomes safe for domestic use after a flow of less than twenty miles, while in other cases the impurities are still present in dangerous amount after a flow of ten times that distance. It is possible, but not probable, that there is actually so great a difference in results as recorded observations seem to show. It is much more likely that the value of such observations is impaired, by the failure on the part of observers to secure the necessary uniform conditions under which the observations should be made. The sewage which pollutes a stream is often all discharged into it at one point, and very generally on one side only of the stream. In most cases it does not become at once fully commingled with the whole volume of water, and may not become so for a long distance below the source of pollution.

We know that the waters of two confluent rivers may flow side by side for many miles, before each loses its identity. Besides, rapids and eddies or whirlpools, may operate to concentrate the impurities at certain points more that at others. It is therefore to be expected that unless observations are made with the greatest care, and in sufficient numbers, and at a sufficient number of points to give correct averages, great variations and contradictory results will be obtained.

In view of these facts, it would seem that the simple plan of conducting experiments on small artificial bodies of water, where the conditions could be controlled and made uniform, would have suggested itself to specialists in this line of investigation; but if this has ever been done, I am unable to find records of the results.

It would seem practicable to make a series of experiments and observations on a small body of contaminated river-water, confined in a vessel or tank, where all the conditions of a flowing river might be so closely imitated as to make the results applicable to the river itself. It would be easy enough to provide means of artificial agitation, corresponding very closely to the current of the river, and to vary the rate of flow or agitation at will; to imitate very closely the form of cross-section and composition of the banks of the natural stream; to study the effects of sunlight and shade, and the influence of heat and cold; to determine whether sediment, in sinking to the bottom, carries with it any considerable amount of impurities or disease-germs, and to study any other phenomena connected with the problem. It ought to be possible in this way to determine with some degree of certainty, in what length of time, under the various conditions, contaminated water becomes pure enough for

domestic use. Also to study the effect of artificial methods of purification under definite conditions. The water in such a vessel or tank could be easily kept so completely commingled, that a few samples under the microscope would give reliable averages.

It might not be practicable to conduct all the experiments at one place, since the transportation of a sample of water from any great distance, might change its normal condition as taken from the river, but the apparatus could be readily moved from place to place as required. To one who is not a specialist in this line of work, it would seem practicable to attain results with a small expenditure of time and money, of far more value than desultory and uncertain tests of the waters of all the rivers in the country.

DR. CURRIER.—Considering brevity as of the first importance, the author has, in the article discussed, given in the fewest words the result of voluminous reports of experiments. In the body of the communication will be found anticipatory answers, however brief, to nearly all of the very many questions put on the evening of November 5th, and to most of the inquiries and statements of those who spoke at the meeting of November 19th, in so far as these related to the subject-matter of the paper.

The allusions to the weighty facts and figures which the supporters of Pettenkoffer's theory produce, were made to show that the "drinking-water theory"—which the author is disposed to favor—is not the only one accepted by sanitarians. These great problems are at best very complex, and not so easily settled as extremists assume. The writer would distinctly state that he believes the harmfulness of polluted water to depend upon the fact that it contains harmful bacteria. No bacteriologist, believing in Koch's doctrines, would hesitate to give preference (so far as the particular sample is concerned) to a drinking-water having a considerable number of harmless bacteria, rather than to one having fewer bacteria, which were, however, of a distinctly infectious kind. We may doubt whether the healthy alimentary tract is vulnerable to the bacteria of disease which are too often contained in drinking-water. It is presumably essential (at least in the majority of cases) that some departure from the state of perfect health of the mucous membrane must exist, in order that, for example, the typhoid bacillus shall, when swallowed, enter the system and produce disease. Yet it is the part of prudence for all to avoid the use of infected water. The introduction of the bacteria of putrefaction and decomposition with our food and drink, is in no wise desirable. The presence of these micro-organisms in the intestine tends to cause the evolution of undesirable gases, by their action upon the substances present; while the amount of salutary digestive potency which they possess, is very unimportant. They are vastly inferior in this respect to the normal digestive secretions.

As for the unusually large number of bacteria found present in the Delaware River, it may be repeated that the copious rains had washed much matter into the streams, and with it many bacteria. A more careful reading of the article would perhaps cause the querist to find the statement, that "one should not infer that the increase of 'typhoid' in Philadelphia was caused by the bacteria which had survived the 100-mile passage down the river." The stream flowing through the old Croton Aqueduct seemed a desirable one to test, since in its course it received no inflow except from the Bronx. The darkness of the conduit would not tend to lessen the number of bacteria present in the flowing water; and over the water a current of agreeable air was passing.

The results of biological examinations of water are considered most satisfactory, when the plates are prepared immediately after the sample is taken. Transportation to a distant laboratory, especially if the water is kept warm, may result in great increase. The high numbers which Professor Leeds found in the waters of the Passaic may have been due to the fact that he failed to plate the water as soon as his samples were taken from the stream. He must admit that Philadelphia would have a purer water supply, if the Delaware River received no contamination whatsoever between the "Water Gap," and the place whence it now draws a large portion of its supply from that river.

That harmful bacteria survive (at least occasionally) a passage of several miles down a stream, seems probable from the facts presented by the recent epidemic of typhoid fever at Albany. There the cases appeared to be almost entirely limited, to the districts where water from the Hudson River was drunk. (See New York papers of January 24th, 1891.)

It certainly is of vital importance, to keep the water-sheds from which we draw our supplies as free from all contaminations as we possibly can. "Only by vigilant and intelligent efforts can lasting and constant purity of the supply be maintained." The Croton supply is a comparatively "excellent water." This is shown by repeated bacteriological and chemical examinations, and furthermore by the very small number of cases of typhoid fever occurring, among those who regularly drink the New York hydrant water.

The author realizes how desirable it is that numerous observers make many examinations of various waters, and that these be frequently repeated through a long period of months or years. Such investigation involves a vast amount of systematized work and a liberal outlay. It is to be hoped that other wealthy States follow the example of Massachusetts in this respect. The results thereby obtained would be of great value.

[Dr. Currier's paper is summarized on page 40.]

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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Vol. XXIV.—February, 1891.

STREET RAILWAY TRACK.

By T. G. GRIBBLE, A. M. I. C. E.

WITH DISCUSSION.

The valuable paper by Mr. E. E. Russell Tratman upon the improvement of railway and street railway track, *Transactions* Am. Soc. C. E., March, 1891, pointed out as regards the latter, the direction which improvements should take, and gave critical descriptions of the various types of construction in use in this country.

The amount of space given by Mr. Tratman to larger railways in his paper left little room for the subject of street railways, and it will be attempted in this paper to pursue that subject somewhat further, and to show the objective points of English practice as compared with those on this side of the Atlantic.

America alone of the civilized nations has given free and full scope to the street railway, perhaps sometimes too much so, but if her municipalities have erred on the side of leniency to corporations at their inception for the sake of progress, they have known also how to make up for it afterwards in rates and taxes.

The tramway is the parent of the railway, but the offspring has so far outgrown the progenitor as to become to some extent its standard for

imitation. Rails like the "Doane" at Boston, for instance, are as heavy as anything on a trunk line, and heavier rails still are being laid on English tramways.

From the Coalbrookdale tram-slabs in 1767 to the first introduction of practical tramway building in England in 1857, by Mr. George Francis Train, the street railway was unknown, except in America. Snubbed by officialism, opposed by vested interests, hampered by prejudice and timidity, tramway development in England has been slow, but in one direction, that of road-bed and track, there has been progress, slow, also, but sure. The heavy vehicular traffic, and latterly the use of steam dummies upon the suburban lines, has compelled the use of a very substantial foundation and support to the rails, and whilst America has been teaching the old country in matters of rolling stock and traction, she is not unwilling under the altered circumstances of modern urban transit to turn over some back pages of English experience in the pathway of the cars.

The roadbed of railways and tramways can be more easily contrasted than compared. The conditions are radically different. On railways the track is always open to inspection and a decayed cross-tie can be replaced or a loose joint tightened up at any time, but on street railways there is nothing for trackmen to do, because there is nothing for them to see until the substructure fails and the pavement has to be removed.

The high speeds and heavy concentrated loads upon railways produce a series of shocks which require an elasticity in the rails not needed upon tramways, even on electric or cable roads.

The wear upon rails in streets is largely due to the vehicular traffic, the action of which is complicated, compared with that of the car wheel.

The interests to be considered in tramway construction are more diverse:

First.—There are the requirements of the municipal authority.

Second.—The interests of the company, as a commercial undertaking.

Third.—The comfort and convenience of the public who use the cars.

Fourth.—The comfort and convenience of the walking and driving community.

The points which street railway builders have aimed at more or less successfully from the first, have been the following:

1. An imperishable foundation, which need not be interfered with for the purposes of renewals.
2. An unyielding rolling surface.
3. A vertical face against which to lay the paving.
4. A minimum of renewals.
5. A minimum resistance to traction.
6. A smooth surface for passing vehicles.
7. A surface which vehicles will not use for running on.
8. A maximum of speed consistent with safety.
9. A minimum of first cost.

In too many cases the last of these objective points has been the greatest if not the only desideratum to the promoter. The comparative stress laid upon one or other of these points has greatly varied according to circumstances of country, of population and of available funds, but at the present time the tendency is toward uniformity. It is felt increasingly that a very few types of construction should be sufficient to meet all the requirements of the different cases which arise in practice. Those, for instance, which demand a continuous support, and those in which an intermittent support would be preferable. Those which call for a heavy or a light rail, and so forth, and it will now be attempted to analyze the foregoing list of subjects historically and critically with a special bearing upon the present-day problems.

The Foundation.

The streets and roads of cities, especially in old countries, have become sufficiently consolidated to receive a longitudinal bed of concrete without subsidence, and in such cases there can be no better material for the foundation, both from the convenient mode of depositing it *in situ* and from its great strength and durability within a few days after being laid. On soft or newly made road bottoms, it would be as imprudent to lay concrete as it would be to place it on railway embankments under locomotives. Electric railways are now frequently carried far out into the suburbs to develop real estate, and extensive road-making is undertaken to receive the track. Made-up ground, if properly drained and exposed to the weather for three years will generally be firm enough to receive concrete, but if the traffic over it has been light, it should first be well rolled with a steam roller.

Where there is any uncertainty as to the supporting power of the ground and concrete is demanded, it should be laid the whole width of the rails and for a short distance outside of them. It should be, moreover, of a sufficient transverse strength to act under partial settlements as a beam; that is to say, to be of a thickness of from 1 to 2 feet, which in this country would cost from $10 000 upwards per mile for foundations alone. Such an outlay as this would be prohibitive and not more effectual than a system of metallic ties at a quarter the cost.

The Eckington and Soldiers' Home Railroad Company of Washington, D. C., are laying a foundation of concrete between wooden cross-ties in the expectation that when the timber decays there will be sufficient supporting surface from the concrete alone, under and around the rail.

The concrete is deposited in a longitudinal trench under the rail, and the cross-ties are placed 15 feet apart, spiked to the rail in the usual manner. The concrete is afterwards packed around the rail for a depth of 3 inches, and the surface is finished off in asphalt. By this means a lighter section of rail can be used to obtain the same wear as in the English system, with 80 to 100-pound rails. The cross-ties furnish a temporary assistance until the concrete has attained its permanent tenacity. By the time they decay there will be no longer any need for them.

The new electric railway at Pittsburgh, which is to be equipped by the Thomson-Houston Company, is laid with a substantial foundation of concrete, making the total cost of single line $30 000, according to the *Street Railway Journal*. A 60-pound Wharton girder-rail is laid on sawn-oak ties, placed 2½ feet apart and bedded on a concrete foundation. The spaces between the ties are filled with broken stone, and topped out with concrete.

Neither of these methods, although great improvements upon the timber-stringer, can be considered satisfactory construction. Even wooden houses of the better class have brick foundations, but this composite street railway building resembles a substantial house of brick built upon a timber foundation.

The first concrete foundation laid in England was in 1870 on the North Metropolitan line, London; where a longitudinal trench 16 inches wide by 9 inches deep was laid under each rail, besides which a 3-inch bed of concrete was laid the whole width of the track. The rails were attached to wooden stringers resting on cast-iron chairs. This system of

foundations was followed by several other cities, and also the method of imbedding cross-ties of timber in concrete; there was, however, a longitudinal stringer resting on the cross-ties to which a flat rail was fastened.

THE DEAS SYSTEM AT GLASGOW, SCOTLAND.

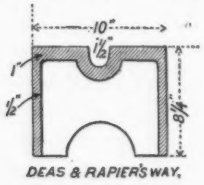


FIG. 1.

Almost at the same time as the London tramway, the Glasgow cast-iron way was laid, Fig. 1, in which, in addition to a longitudinal bed of concrete 18 inches wide by 6 inches deep, the cast-iron box was itself filled with concrete. This foundation has proved very satisfactory on a ten years' trial; although in some few cases, under the heaviest traffic of the wharves, a slight settlement took place, necessitating the lifting of the box.

A longitudinal bed of concrete has not only the advantage of less disturbance of the street when first laid, but it can be conveniently applied for replacing a wooden system by a metal and concrete one without interrupting the traffic. The wooden stringer can be underpinned with concrete during the daytime, and the iron stringer substituted during the short interval of night when the cars have ceased running.

As the use of Portland cement concrete for street railways, except for cable roads, is only in its first stages in America, it is greatly to be hoped that proper justice will be done to this most valuable material. The work of testing the cement, mixing the ingredients, and depositing the concrete, should be under an inspector who cannot be bought by the contractor. It is easier to "scamp" concrete than any other part of the work. On a work of sufficient magnitude there should be a cement-storing shed, with a testing office attached. There should be also a mixing machine, and facilities for rapid delivery of the material. Some contractors will, if not carefully watched, not only give short allowance of cement but work up leavings, half-set or quite set, into a fresh mixing.

A proportion of one of Portland cement to five of sand and gravel

or broken stone, is suitable to this work. It has a tensile strength of about 50 pounds per square inch after a week, increasing up to about 150 pounds, when a year old and upwards.

The crushing strength of the concrete itself is so greatly in excess of the loads that can come upon it, that failure never takes place in that manner when it is properly laid.

It is always a subsidence of the soil beneath the concrete which causes trouble, making it into a beam under transverse stress. An area of good soil forming a longitudinal support to the concrete under each rail 15 inches in width is approximately equal to the bearing surface under cross-ties 9 feet long by 9 inches wide, spaced 2 feet 9 inches apart. As this is sufficient to support heavy locomotives, it may be taken as sufficient for street railway motors where the ground is good. In conclusion, it may be remarked that the tendency of the best practice is to dispense with all timber underground. A wooden cross-tie under a steel rail and granite pavement, is as much out of place as would be a foundation of crib-work under a handsome house of dressed ashlar.

The Rail Supports.

The timber system of stringers resting on cross-ties to which they are fastened by cast-iron knees, is too well known to need description. It forms a striking contrast from the most advanced practice in England at the present, where the rail has no intermediate support whatever. Weighing, as it does, from 100 to 120 pounds to the yard, it rests upon a longitudinal bed of concrete which covers its flanges and maintains it absolutely immovable. It requires no tie-rods even on curves, and in renewing it the pavement need not be disturbed beyond the width of the base of the rails—6 or 7 inches. When taking maintenance and renewals into account, this method is cheaper in the long run than the wooden stringer, especially where the street is paved with granite. If companies using timber could be induced to give the cost per mile of repairs, carried out as they are, piece by piece, as trouble arises, it would probably account for the excessive "working expenses," so-called, which have placed many of them into the hands of a receiver. On the other hand, this huge self-supporting rail cannot be called economical. Supposing the head, which is the only wearing surface, to have a life of seven years, it will then have lost in one yard's length about 5 or 6 pounds of iron by attrition, and since it weighs 120 pounds, about 94

to 96 per cent. of the section, perfectly unworn, will have to go to the scrap heap.

This is a startling change from the parent tramway of Coalbrookdale, where a century ago the Coalbrookdale Iron Company laid down upon wooden stringers their surplus stock in slabs, still treasuring them as an asset, to be used up when they ran short.

The Goliath girder-rail is not, however, the first attempt at a self-supporting way, and the following system, though not extensively used, is well deserving of notice, because it was the first to present the element of a maximum stability:

The Deas and Rapier System.

As early as 1870 the tramway already referred to was laid in Glasgow, Scotland, by Mr. Deas, engineer to the Clyde trustees, in which the rail formed the upper portion of a cast-iron box filled with concrete, and resting upon a lower bed of concrete. The wearing parts were chilled, and stood the heaviest traffic of the wharves of the city very successfully. The sides formed a vertical wall to the paving, and the concrete, being laid in a longitudinal pit, made comparatively little disturbance of the road surface. The boxes were cast in 5 feet lengths, filled bottom upwards, and then lowered into place with tackle. Tie-rods were at first used, but afterwards abandoned as unnecessary. The blocks remained perfectly stable by their own inertia. The disadvantages of the system were:

First.—The blocks were heavy to handle.

Second.—The concrete having set in, the boxes did not form a bond with the bottom layer.

Third.—In order to renew the track, the whole cast-iron box, 90 per cent of which was unworn, had to be sacrificed, together with its filling of concrete.

The great width of rail surface was adopted in order to enable the company's drays to use it equally with the flanged car wheels. The material used was evidently in excess of the actual requirements, because there was ample support to the rail in the internal concrete, without bringing down continuous heavy metallic sides. It is also evident that the arrangement of the material in the double web form, instead of in one central web, should not lead to extravagance but to economy of material. The girder form of rail or flanged tee-rail, as it

should be more properly called, requires a thickness of web not only sufficient to resist the direct static stresses developed within it by the load, but also to resist the torsional stresses produced by its comparatively low stability. The box girder or twin web by its geometrical form possesses so much greater stability, that it can afford, with the same weight per yard forward, to let some of its material go to an increase of depth, and so form not only a stiffer but a stronger rail, especially when the space between the web is occupied by a filling which precludes the possibility of buckling of the web. The stability in the Deas rail arose from the weight of the cast-iron and enclosed concrete, assisted by the adjacent paving, but as there was no bond with the lower concrete, this was all. The support of the adjacent pavement is not an easy thing to calculate, and considering that it is sometimes removed during traffic, it is safer not to make any allowance for it.

Comparing the stability of a 5 feet length of the Deas pavement with and without cohesion of the upper and lower concrete, we will assume the concrete to have been made of 1 of cement to 5 of gravel, the box being 10 inches wide by 8¼ inches deep, 203 pounds per yard.

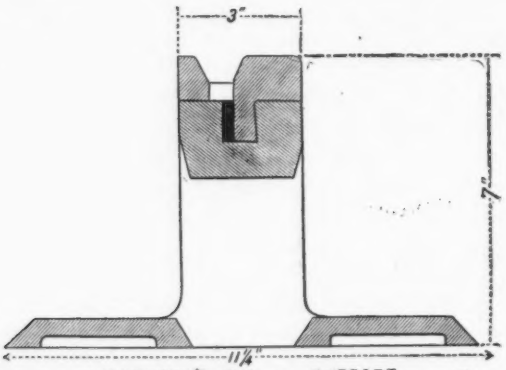
Without any cohesion the force applied at rail level necessary to overturn the block would be 349 pounds. Properly bonded, at the end of a week, the force necessary would be 12 600 pounds. At the end of a month it would be 18 350 pounds.

These figures go to prove that if the concrete were made to cohere, the only disturbing force would be one sufficient to overturn the whole structure with its foundations, or to force it sideways through the paving, and, consequently, how easily a vastly increased stability, even with a much narrower box, might have been obtained.

Mackison's Way.

An improvement upon the Deas system is seen in the Dundee tramway of 1880. The cast-iron box with close sides is replaced by a series of nearly continuous open-framed boxes 3 feet 11 inches long, laid in line under each rail. The spaces between the standards of the frame are packed with concrete from the sides and ends, but both the top and bottom are continuous plates, the lower one 11¼ inches wide and the upper 3 inches wide. The rail is of the grooved central web type, having longitudinal slots cut through the floor of the groove, into which wrought-iron keys are inserted and driven up against the center web.

This latter is rolled with a taper, and is retained in place by the keys. They can be struck and the rail removed without disturbing the pavement. The spaces in the slots between the wedges are filled with asphalt. The whole width of track and somewhat outside of it rests upon a bed of concrete 6 inches deep. The best features of this system appear to be the concrete foundation, the continuous support, and the



MACKISON'S RAIL AND SUPPORT.

FIG. 2.

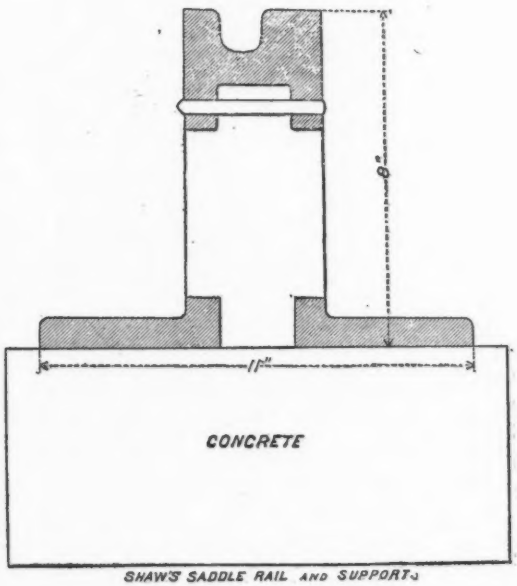
removable rail. The cutting of a slot, on the other hand, must be deemed a drawback to the rail, and the central web not being required for transverse stress, can only be regarded as a means of attachment, and, similarly to the Deacon rail, involves a considerable amount of superfluous material between the attachments.

QUANTITIES AND COST AT AMERICAN AVERAGE PRICES OF MACKISON'S SYSTEM FOR ONE MILE OF SINGLE TRACK.

Steel rails, 36 pounds per yard, 56½ tons, at $44.80	$2 531 20
Wrought-iron keys, 2 170 pounds, at six cents	130 20
Cast-iron stringers, 141½ tons, $33.60	4 753 40
Lifting and carting away macadam, 522 cubic yards, at fifty cents	262 00
Excavation, 1 108 cubic yards, fifty cents	554 00
Concrete, 6 inches thick, 782 cubic yards, $5	3 910 00
Laying track, 1 760 lineal yards, sixty cents	1 056 00
Royalty	365 00
Total for the way, exclusive of paving	$13 561 80

The Shaw System.

Shaw's system at Manchester, Eng., consists of a saddle rail resembling the Lewis & Fowler (Fig. 17), but instead of isolated chairs a continuous, or nearly continuous, cast-iron stringer supports the rail. The stringers are 4 feet 11 inches long, and are laid 1 inch apart longitudinally. They weigh 117 pounds each. The rail, 45 pounds in weight, is of the ordinary box or saddle section attached by the side flanges with



SHAW'S SADDLE RAIL AND SUPPORT.

Fig. 3.

spikes driven through hardwood plugs. The bottom beds of concrete are 15 inches wide by 5 inches deep, and concrete is packed up sideways under the rail so as to form a wall to the paving. The combined weight of rail and casting make 116 pounds of iron per lineal yard.

QUANTITIES AND COST AT AMERICAN AVERAGE PRICES OF SHAW'S SYSTEM FOR ONE MILE OF SINGLE TRACK.

Steel rails, 45 pounds per yard, 70 tons, at $44.80....	$3 136 00
Cast-iron stringers, 70 pounds per yard, 110 tons, at $36 60.....	3 696 00
Spokes, 1 570 pounds, at four cents.....	62 80
Wooden plugs, 6 160, at one cent.....	61 60
Concrete, 204 cubic yards, at $5.....	1 020 00
Surface excavation, 8 inches deep, 1 109 cubic yards, at fifty cents	554 50
Total cost of way, exclusive of paving.....	$8 530 90

The amount of concrete depends upon the nature of the ground. If the same quantity of concrete were used as in Mackison's system, it would bring up the cost to $11 420 per mile.

In both the Shaw and Mackison systems, there is little or no cohesion between the concrete packed into the stringer and the bottom bed; they are separated by the bottom plate of the stringer. The concrete filling has to be packed in from the sides, which is a difficult matter to do satisfactorily.

The advisability of a continuous or an intermittent support to the rail, depends upon the character of the road and the condition of the ground. The wooden stringer offers a continuous support, and works well as long as it lasts. It is economical, because the flat rail carried by it is cheaper than the girder-rail. The girder-rail, with intermittent supports, is coming more into favor in this country, whilst the same class of rail is laid in England on a continnous bed of concrete. The paving blocks in England are not so deep as in America. There the average is 7 inches deep. A great deal of heavy traffic is carried on 6-inch blocks, and probably 7½ inches is the deepest, whereas here the blocks run 9, 9½ and even 9¾ inches deep. A rail 10 inches deep would be too extravagant, therefore the use of chairs of cast-iron, wrought iron or steel to keep it off the paving. It cannot be claimed for the principle of intermittent supports that it is needed to produce elasticity, because perfectly rigid tracks like many of those in England, wear just as well as those having elasticity, and they wear the paving less. A very elastic street track will soon shake up the adjacent paving and cause its rapid destruction.

Chairs are usually set upon wooden cross-ties in this country, the objections to which have already been referred to. Probably before long

they will give place to metallic cross-ties, which are already in the market. Mr. Tratman's paper takes up this subject, but it may be added that steel ties for tramways and light railways in British colonies are being largely manufactured in England. They have no chair, but the rail is attached direct to the tie by its flanges. The ties are stamped out of mild steel plate by a machine furnished with a punching die, which leaves a lug to catch one flange and a bolt-hole opposite it to receive a clip-bolt for the other flange. The Indian State railways use mostly a tie with a reversed vertical curvature, so as to form a kind of bridge in itself, and with flared sides, but for smaller railways plain channels are used. Several types of these are made by the Johnson Company; one of them is made out of a pair of angle irons connected by short plates, so as to leave an opening lengthwise for tamping the ballast.

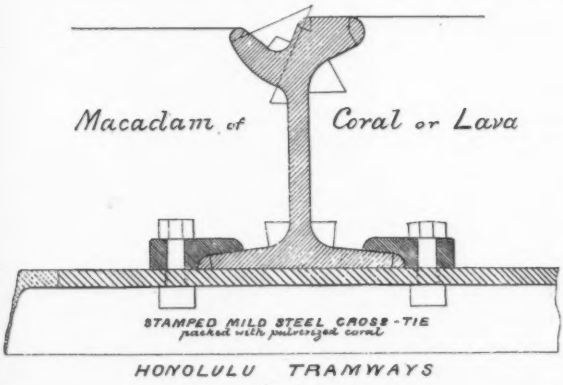


FIG. 4.

The rail illustrated in Fig. 4 was used by the author upon the 12-mile tramway of the City of Honolulu. An unreasonably rigorous stipulation in the franchise called for a flush surface inside and outside of the track, although no paving material was procurable within 2 000 miles. Timber decays in that climate in from one to three years. The girder-rail was adopted with as easy a groove as permissible, bolted by its flange to mild steel cross-ties, packed with pulverized coral. Cement concrete was first used until it was found that the coral made as good a packing. The road was macadamized with either coral or hard lava-rock, rolled down after the track was laid by a 15-ton steam roller which

produced no settlement upon the track. To prevent the stone being crushed into and wedging up the groove when being rolled, it was filled half full of volcanic sand and then covered with loam, which formed a very hard crust over it under the roller. This filling resisted the tropical rains and all the vehicle traffic for several months until the line was ready for opening, but was easily removed when required for use by a man with a pick, who cracked the crust and ripped out the filling almost as fast as he could walk. This furnishes the idea for a protected lug or key-seat in the suggested system to be described later on.

Chairs are made of cast-iron, mitis steel, or drop-forgings. Cast-iron chairs have fallen into great disfavor here on account of their liability to breakage in spiking. They are still in general use on trunk lines in England, where, for spiking, a hollow "trenail" of compressed wood, generally oak, is sometimes driven into a hole bored in the tie, and a cylindrical spike or drift-bolt then driven through so as to force the fiber of the trenail into that of the tie and form a perfectly tight and very durable fastening. With metallic ties, cast-iron chairs are not objectionable, except on the ground of difficulty in securing a perfect fit to the flange of the rail. The Johnson Company make a mitis steel chair which supports the rail in a very thorough manner, fitting it under both sides of the head and both edges of the flange, and is keyed up tight by a cast wedge having a splice-bar fit.

The use of this valuable material, mitis iron and steel, will probably be extended by the reduction in price of aluminium, and be largely used in rail fastenings. It is perfectly malleable, though not rendered so by the old process of annealing. It is an excessively mild steel, having the properties of wrought-iron in greater or less degree, according to the proportion of high grade iron in the mixture.

The drop-forged chair in common use for merely holding the flanges of the rail, has a pair of lugs at opposite ends, so that by twisting the chair sideways it can be inserted under the rail, and then by twisting it square the lugs are brought to bear upon the flange. When this chair rests on a wooden tie, the loosening of the spikes will be liable also to loosen the hold of the lugs.

A chair with one lug and a bolt and small clip opposite to it for holding a flange rail, occupies a little more time in attachment, but is more satisfactory, as being independent of the lower fastening to the tie.

Other chairs are made to fit the web of the rail as well as the flange,

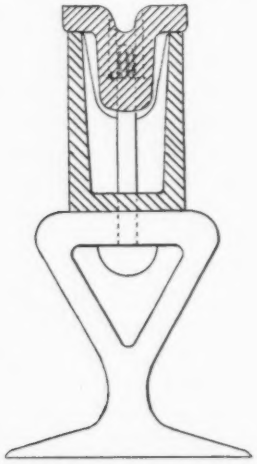
and are called brace-chairs. The chair proper is a flanged channel under the base of the rail, from the side of which a clip is carried around the flange of the rail and up the web on one side, whilst a cast-iron clip is bolted in to the other. It will be observed that there is no bolt through the web of the rail to hold the clips up against it. The chairs are intended to be placed at any part of the rail, so that a through bolt would be impracticable, but in the absence of them there cannot be a very strong hold upon the web of the rail. In the case of the flangeless tee-headed rail, however, the Johnson Company use a complete splice-bar fit with a through bolt. This involves piercing the rail wherever a chair occurs, but is obviously needed in order to obtain a good hold upon the rail.

An improvement in construction is to be found in the Lewis and Fowler chair. It arises from the prior improvement in the form of the rail. Without forestalling the subject of rails, it will be noticed that the adoption of the double-webbed rail, at once admits of a form of chair which has greater inherent stability. A distance-piece inside the chair keeps the sides apart, whilst the two bolts draw up the sides of the rail against the chair, by an elongated jaw-washer, which holds a lip on the rail down to a lip on the chair. The vertical stress of the car wheel at the joint passes directly to the chair, and through the chair to the tie, the jaw-washer is not intended to perform the duty of a splice bar, it merely acts as a fastening. The chair is itself a bridge and an abutment in one, having the whole depth available for construction with which to resist deflection. There appears, however, to be no connection between the upper portions of the chair under the rail. These flanges would, therefore, possess but little strength, and might be dispensed with in their present form. In the Johnson chair the depth available is from the base of the rail to the tie. There is on the one side a clip, which completely surrounds the rail and must be exceedingly carefully fitted as shown in Fig. 15, on the other side there is a channel splice-bar, slightly bridged in order to give grip to the four bolts. The company lay great stress upon the splice-bar fit, but the use of a supported joint as shown, is an evidence against the sufficiency of the splice-bar. A stress which is carried by a splice-bar puts the latter into transverse strain at the joint; producing longitudinal stresses of compression in the upper and tension in the lower extremity, consequently a deflection, more or less, of the rail at the joint. The bolts being approximately at the neutral axis are not materially affected.

With a supported joint upon a chair of the form shown, the stress passes directly through the chair to the tie, and being much stiffer than the splice-bar, the chair will carry nearly all the stress. It would appear possible in the Lewis & Fowler chair to form an alliance for mutual support between the upper ends of the chair, as shown in Fig. 17, and so to entirely underpin the rail, whereas in the Johnson joint, the free ends of the clip and splice-bar, unless the rail is pierced, afford an inconsiderable support to the rail as compared with the amount of material in them.

The Deacon System at Liverpool, England.

In the Deacon system, at Liverpool, Eng., a grooved, reversible rail was used, resting on a continuous cast-iron box, to which it was bolted at its center. A greater proportion of the iron was here made effective for wear and the vertical wall for the paving was preserved.



DEACON'S REMOVABLE RAIL

Fig. 5.

Having no internal concrete, the box lacked the stability of the Deas system, and required to be supported on wide iron chairs. The central bolt attachment was made by screwing down a phosphor bronze nut and surrounding it with red lead. Consequently the rail had to be

much deeper than was needed for actual wear. Mr. Deacon laid great stress upon the fact of the permanency of his cast-iron box, and its forming a suitable wall for the paving. The attachment was found satisfactory, one man with a chisel-pointed wrench was able to put a pull of 2 tons upon the bolt, which was slot-headed, and the nut-chamber was kept free from corrosion by a filling of plastic pitch. The rail was not intended to be reversed, but to be used with car wheels having central flanges and double treads. The rail, in itself, has sufficient material to carry a load between intermittent supports, although it rests upon the casting throughout. The great bulk of the central portion was to give covering over the nut, and the rails had to be drilled and the chamber turned out so as exactly to fit the bolts in the casting. One would think that a slight mistake in the spacing might produce great expense and inconvenience.

The Rail Material.

Cast-iron is not now used for rails. Probably the only and the last tramway laid with a cast-iron rolling surface was the Glasgow system of Mr. Deas. It was satisfactory in point of durability because in it a surface of very great hardness, chilled cast-iron, not under transverse stress, was placed in suitable conditions for service as a rail. The disadvantages of that system have already been touched upon, but it remains as a suggestive illustration of the fact that in positions where an elastic girder under transverse stress is not required, a material may be used which is better adapted for resisting attrition than the usual mild steel employed in rails.

By tempering or case-hardening steel, a surface may be obtained which is three times harder than ordinary mild steel, but without tempering, the amount of carbon used in the making of the steel will vary its hardness 100 per cent.

The steel usually adopted for street railways is similar to that for larger railways, and the specifications generally call for about .25 to .30 per cent. of carbon with hot-bending and cold-bending tests for tensile strength, elongation and ductility, as stringent in every respect as those of the best trunk lines.

It is, however, a perfectly different treatment of the steel to support it as a flat rail continuously, from what it receives under the conditions of an ordinary railway. The life of rails shows this when compared under varying speed of travel. A rail only under slowly rolling loads

will possess two or three times longer life in tonnage than one subjected to high speed engines. It is the shock that tells. At the moderate speeds permissible upon city and suburban lines, upon a continuously supported rail, there is no transverse stress and no danger of breaking a rail. Nothing but a rubbing down of the surface, which may be made as hard and brittle as tool steel without any danger.

Tool steel has a percentage of 0.6 to 1.2 of carbon, and its hardness is double to treble that of rail steel. The view is here submitted, that the life of street railway track might be doubled without any danger of accident and with little extra cost. As an illustration, the tongues of movable switches, being under concentrated shocks on thin edges, are made of shear steel of great hardness, but being continuously supported, are quite safe.

In the streets of a busy thoroughfare, the rails are worn nearly as much by the vehicles as by the car wheel. The following series of worn sections will show this very clearly, and also the comparatively small difference between the wear of the iron and steel. They exhibit the wear due to traffic in the City of Glasgow on two of the busiest thoroughfares, one on the north and the other on the south side of the River Clyde. The first pair of rails were down six years and five months, and the second pair six years.

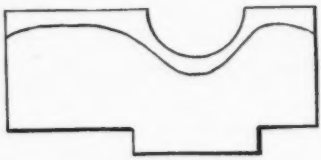


FIG. 6.

Iron rail in wear for six years and five months; original weight, 60 pounds per yard. Lost 0.858 pounds per yard per annum.

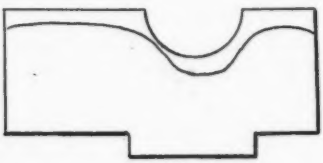


FIG. 7.

Steel rail in wear for six years and five months; original weight, 60 pounds per yard. Lost 0.849 pounds per yard per annum.

These diagrams were taken from Mr. Clark's standard work on "Tramways," who gives the original sections and the worn sections separately. In superimposing them as shown, to exhibit the wear graphically, the amount of wear does not correspond exactly with the numerical results, but will serve to give a general idea of a matter, which must vary much according to the nature of the traffic and the composition of the rail. There are unfortunately no data of the relative chemical composition of these rails, but seeing that they were alike continuously supported, it would appear that the ratio of wear was identical with the ratio of hardness.

The wear of steel rails on larger railways is also unsatisfactory, considering the possibilities of that material. Allowing for great differences of opinion amongst engineers, arising from different conditions of speed,

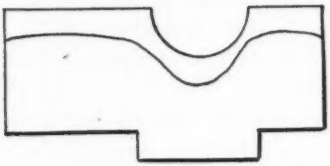


FIG. 8.

Iron rail in wear for six years; original weight, 60 pounds per yard. Lost 0.811 pounds per yard per annum.

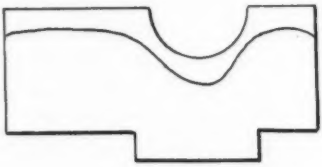


FIG. 9.

Steel rail in wear for six years; original weight, 60 pounds per yard. Lost 0.689 pounds per yard per annum.

spacing of cross-ties and ballasting, giving sometimes very conflicting results; the fact remains that hard steel rails do not realize the durability under heavy traffic which their hardness would lead us to expect.

At the meeting of April 6th, 1874, of the Inst. C. E., in London, many valuable data were produced upon this matter. Mr. Josiah Tim-

ing any tension. It is claimed that such worn rails can be made reliable only by planing off the crystallized portion, after which the worn head will do duty as a tension member, and the new head never shows any signs of fatigue from its former duty as a tension member.

As a matter of fact, the reversibility of a rail is not of much value under those circumstances.

A rail, Fig. 10, 4 inches deep on a 4-foot bearing and loaded in its center with 2 tons, will be under a horizontal compressive stress of 3 tons in the head. Independently of this, a vertical force due to impact, varying in its intensity directly as the elasticity of the rail and inversely as the elasticity of the springs, will act upon it with a possible force of

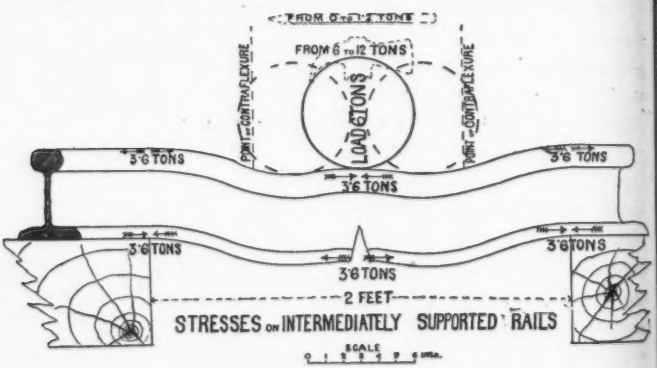


FIG. 11.

4 tons. Thirdly, the abrasive force of friction may be anything from a few pounds to half a ton.

This simultaneous action of forces may be illustrated by supposing them increased so as to destroy the rail, which would then be deflected, as shown on Fig. 11, which represents a heavy locomotive wheel on a heavy rail. The lower fiber has parted and the upper fiber has bulged. The wheel acting as a hammer upon the bulged fiber quashes it, and when leaving it, acts like a file and rubs it off.

It is probable that the molecular action of fatigue, which is most severe under alternating stresses or simultaneously applied diverse stresses, is analogous with the action of destruction shown on Fig. 11. Although the fiber may not bulge, the particles in the upper surface are pressed together with great force, thus assisting the abrasive action.

When passing on a rapidly moving train from a worn and badly kept piece of track to a newly laid section, the rhythmic measure of the car wheels is suddenly exchanged for a steady roll, showing that the wear of the old track has been intermittent like the supports.

The proposed "Sayre" rail, illustrated in Mr. Tratman's paper, shows a marked increase in the depth of the head, probably to meet these concentrated forces; whilst Mr. Sandberg's Goliath rail has greater width. Deepening the head brings the neutral axis further up the section, and renders the lower portion of the head of little value in resisting the compressive horizontal stress. Statically considered, the wide head makes a more efficient girder than the deep one.

The rapid wear of rails upon rigid intermediate supports, such as chairs, may be illustrated by the following exaggerated diagrams. In

FIG. 12.

the first case, Fig. 12, there is a sharp and contrary curvature between each pair of supports, whereas, when the supports are flexible and yield somewhat to the load, a gradual curvature is formed, which makes a less demand upon the ductility of the rail.

FIG. 13.

A continuous support on the other hand may be quite rigid under high rates of speed. On the Great Western Railway of England, trains run at 60 miles an hour over a bridge rail resting on a longitudinal wooden sleeper, which is bedded upon about 2 feet of stone ballast. It makes a very economical track as regards the rail, because a light section is used to carry the heaviest traffic. It is also a safe track, because there are no bolt holes in the rail and no danger of breakages. The company maintains the system on the main lines, but the branches are laid with cross-ties, the reasons being the higher price of timber for longitudinals, and the disadvantage of having to remove the rail when renewing the sleeper.

The Rail Section.

The rails in use at the present time, or which have been used with any degree of success, may be classified as follows:

First.—The tee-rail, with flanges, or Vignoles rail.

Second.—The girder-rail or Vignoles rail, with groove or tram.

Third.—The tee-rail, without flanges.

Fourth.—The box-rail.

Fifth.—The flat rail.

The common tee-rail has been considered in Mr. Tratman's paper, and will not be dwelt upon in this paper, except to compare it later on with the box-girder principle. It is an easy rail to run on, and where city authorities permit it, the tramway company may consider itself lucky. Generally, if allowed at all, it is only on sufferance in partially developed suburbs, and the company is sometimes compelled to replace it with a different type earlier than they expected.

With regard to the girder-rail, with or without bottom flanges, quite a number of designs have been tried and are still in the market. They differ not only in outward form, but in their essential properties of strength and stiffness. It would seem as if their designers did not always make the theoretical perfectness of the rail the starting point, since so much of the section is designed merely to make a suitable attachment, as, for instance, in the Deacon rail (Fig. 5). The street rail cannot maintain the same symmetry of figure and theoretical perfectness of the railway rail, but it can approximate to it very closely. Two essential points about a girder-rail when laid against paving, are that:

1. The vertical stiffness or resistance to deflection is of prior importance to its strength.

2. The torsional stability of a rail cannot be efficiently supplied by vertical depth of attachment; it needs lateral width in order to give moment of resistance.

Two rails of the flange and flangeless type will be presently compared as to these points, but a word of introduction may be prefaced to supply the history.

The flangeless tee-rail seems to have made its first appearance in 1870 in the Cockburn-Muir system at Montevideo, where it was laid on longitudinal cast-iron sleepers, about 12 inches long, and about 3 feet 6 inches apart from center to center. It was followed by the Barker

system at Manchester in 1877. There the shank of the rail was housed in the chairs by a close-fitting joint and fastened transversely by a gib and cotter.*

The Meakins rail (Fig. 14) in South London, laid in 1880, consisted of a flangeless tee weighing 52 pounds per yard, sandwiched between a pair of angle irons, making up the total weight per yard forward to 112 pounds.

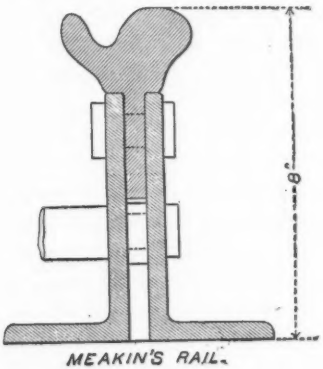


FIG. 14.

Although distinct from its support, the rail was not designed to be renewable separately, being attached to the angle irons by ¾-inch rivets, at 6-inch pitch.

The Deacon rail already alluded to, also resembles a flangeless tee. It was laid in 1877–78.

The Johnson Company of Johnstown, Pa., has introduced a bulb tee, which is not only an improvement on the flangeless tee as regards the fastening, but makes a much stronger rail. It is still, however, far behind the flanged girder-rail. The following comparison of two rails in their catalogue will show in a striking manner the loss that a girder sustains, by robbing it of its "understandings":

No. 131 (Fig. 15) is a 78-pound rail with tram head and bulb foot.

No. 207 (Fig. 16) is an 80-pound rail with groove head and flange foot, reduced to a 78-pound section by slightly narrowing the bottom flange. It is 0.8 centimeter longer.

In the bulb-rail, the neutral axis is almost in the head itself, so that

* For cuts of these, see discussion by Mr. Gribble.

ing any tension. It is claimed that such worn rails can be made reliable only by planing off the crystallized portion, after which the worn head will do duty as a tension member, and the new head never shows any signs of fatigue from its former duty as a tension member.

As a matter of fact, the reversibility of a rail is not of much value under those circumstances.

A rail, Fig. 10, 4 inches deep on a 4-foot bearing and loaded in its center with 2 tons, will be under a horizontal compressive stress of 3 tons in the head. Independently of this, a vertical force due to impact, varying in its intensity directly as the elasticity of the rail and inversely as the elasticity of the springs, will act upon it with a possible force of

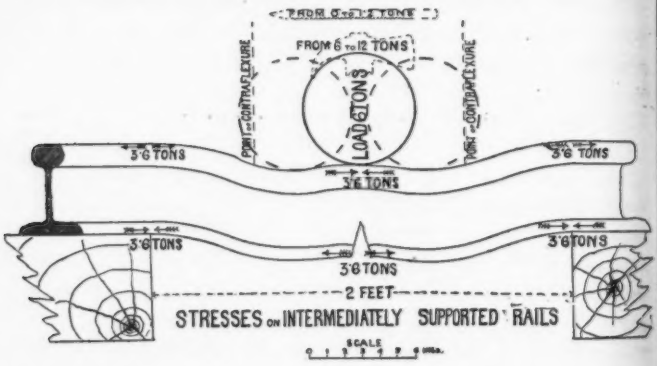


FIG. 11.

4 tons. Thirdly, the abrasive force of friction may be anything from a few pounds to half a ton.

This simultaneous action of forces may be illustrated by supposing them increased so as to destroy the rail, which would then be deflected, as shown on Fig. 11, which represents a heavy locomotive wheel on a heavy rail. The lower fiber has parted and the upper fiber has bulged. The wheel acting as a hammer upon the bulged fiber quashes it, and when leaving it, acts like a file and rubs it off.

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The proposed "Sayre" rail, illustrated in Mr. Tratman's paper, shows a marked increase in the depth of the head, probably to meet these concentrated forces; whilst Mr. Sandberg's Goliath rail has greater width. Deepening the head brings the neutral axis further up the section, and renders the lower portion of the head of little value in resisting the compressive horizontal stress. Statically considered, the wide head makes a more efficient girder than the deep one.

The rapid wear of rails upon rigid intermediate supports, such as chairs, may be illustrated by the following exaggerated diagrams. In

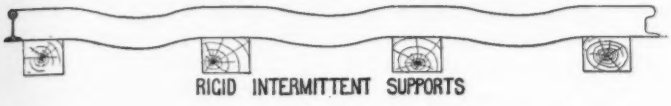


FIG. 12.

the first case, Fig. 12, there is a sharp and contrary curvature between each pair of supports, whereas, when the supports are flexible and yield somewhat to the load, a gradual curvature is formed, which makes a less demand upon the ductility of the rail.

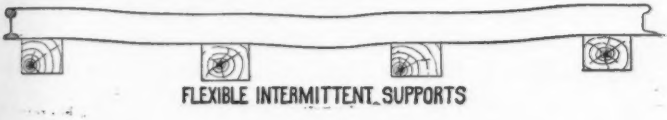


FIG. 13.

A continuous support on the other hand may be quite rigid under high rates of speed. On the Great Western Railway of England, trains run at 60 miles an hour over a bridge rail resting on a longitudinal wooden sleeper, which is bedded upon about 2 feet of stone ballast. It makes a very economical track as regards the rail, because a light section is used to carry the heaviest traffic. It is also a safe track, because there are no bolt holes in the rail and no danger of breakages. The company maintains the system on the main lines, but the branches are laid with cross-ties, the reasons being the higher price of timber for longitudinals, and the disadvantage of having to remove the rail when renewing the sleeper.

The Rail Section.

The rails in use at the present time, or which have been used with any degree of success, may be classified as follows:

First.—The tee-rail, with flanges, or Vignoles rail.

Second.—The girder-rail or Vignoles rail, with groove or tram.

Third.—The tee-rail, without flanges.

Fourth.—The box-rail.

Fifth.—The flat rail.

The common tee-rail has been considered in Mr. Tratman's paper, and will not be dwelt upon in this paper, except to compare it later on with the box-girder principle. It is an easy rail to run on, and where city authorities permit it, the tramway company may consider itself lucky. Generally, if allowed at all, it is only on sufferance in partially developed suburbs, and the company is sometimes compelled to replace it with a different type earlier than they expected.

With regard to the girder-rail, with or without bottom flanges, quite a number of designs have been tried and are still in the market. They differ not only in outward form, but in their essential properties of strength and stiffness. It would seem as if their designers did not always make the theoretical perfectness of the rail the starting point, since so much of the section is designed merely to make a suitable attachment, as, for instance, in the Deacon rail (Fig. 5). The street rail cannot maintain the same symmetry of figure and theoretical perfectness of the railway rail, but it can approximate to it very closely. Two essential points about a girder-rail when laid against paving, are that:

1. The vertical stiffness or resistance to deflection is of prior importance to its strength.

2. The torsional stability of a rail cannot be efficiently supplied by vertical depth of attachment; it needs lateral width in order to give moment of resistance.

Two rails of the flange and flangeless type will be presently compared as to these points, but a word of introduction may be prefaced to supply the history.

The flangeless tee-rail seems to have made its first appearance in 1870 in the Cockburn-Muir system at Montevideo, where it was laid on longitudinal cast-iron sleepers, about 12 inches long, and about 3 feet 6 inches apart from center to center. It was followed by the Barker

system at Manchester in 1877. There the shank of the rail was housed in the chairs by a close-fitting joint and fastened transversely by a gib and cotter.*

The Meakins rail (Fig. 14) in South London, laid in 1880, consisted of a flangeless tee weighing 52 pounds per yard, sandwiched between a pair of angle irons, making up the total weight per yard forward to 112 pounds.

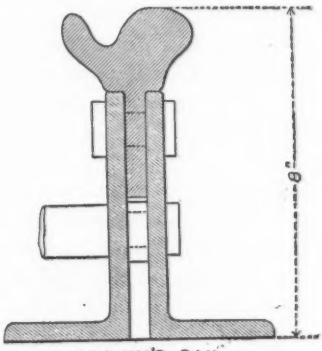


FIG. 14.

Although distinct from its support, the rail was not designed to be renewable separately, being attached to the angle irons by ¾-inch rivets, at 6-inch pitch.

The Deacon rail already alluded to, also resembles a flangeless tee. It was laid in 1877–78.

The Johnson Company of Johnstown, Pa., has introduced a bulb tee, which is not only an improvement on the flangeless tee as regards the fastening, but makes a much stronger rail. It is still, however, far behind the flanged girder-rail. The following comparison of two rails in their catalogue will show in a striking manner the loss that a girder sustains, by robbing it of its "understandings":

No. 131 (Fig. 15) is a 78-pound rail with tram head and bulb foot.

No. 207 (Fig. 16) is an 80-pound rail with groove head and flange foot, reduced to a 78-pound section by slightly narrowing the bottom flange. It is 0.8 centimeter longer.

In the bulb-rail, the neutral axis is almost in the head itself, so that

* For cuts of these, see discussion by Mr. Gribble.

the mass of iron forming the tram of the rail furnishes very slight resistance. Moreover, the center of gravity is not midway in the web, but at the extreme right, thus giving it an inherent disposition to cant. The flange-rail has its center of gravity in its center of figure, that is to say, it bisects the rail lengthways and breadthways, or nearly so. The bulb-rail has a moment of inertia of 835 centimeters, and the flange-rail 1 603. Comparing the former figure with the deflection under proof-load recorded in the catalogue. A load of 62 000 pounds applied on a 24-inch span, produced a deflection of 0.027 inch. Assuming the load to have been applied in the center and the ends supported but not fixed, a moment of inertia of 835 centimeters would correspond with a modulus of elasticity of 32 965 000 pounds, which is a good average for rail-steel, and checks the computation.

Tests of the flange-rail are not recorded, but with the same modulus it would have a deflection under similar conditions of loading of 0.014 inch, or about 52 per cent. of that of the bulb-rail.

As regards stability, when fastened to a chair, the bulb-rail has only the stability due to the resistance to bending of the plate at the throat marked *A*, and the perfectness of the fit of the bolts. The flange-rail has inherent stability. In order to cant, it must rotate upon one of its flanges, and in so doing lift either the clip or the brace which opposes a resistance having a leverage of nearly the width of the base of the rail.

The second condition, previously mentioned, of an unyielding rolling surface, is only fulfilled thoroughly by a continuous support; but where an intermittent support is used, the flange girder-rail is always more efficient, and consequently more economical than the flangeless tee or the bulb-rail.

The fourth type of rail, termed usually the box-rail, has formed the subject of numerous ancient and modern patents. Whilst treating of the rail supports of the Lewis & Fowler rail, it has been pointed out how the double-webbed rail affords increased stability with the same amount of material.

The earliest types of box-rail will only receive a passing comment. In some cases, the two webs form part of the rail, in others they are distinct rails, but fastened together. The first approach to the box-rail was the Larsen saddle-rail, at Dublin, which had a continuous support, its form being selected to substitute a side fastening for a central one, its stiffness, however, demonstrated the practicability of its being intermittently supported.

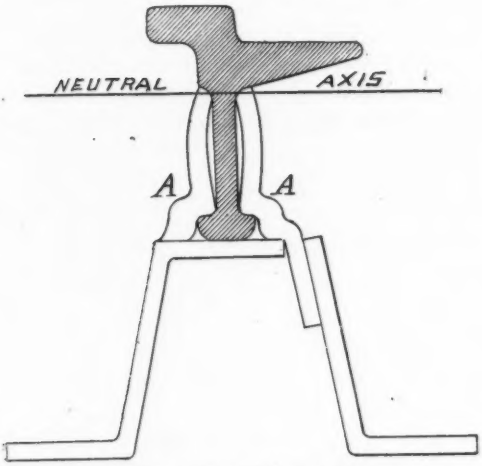


FIG. 15.

Weight per yard (rail only) 78 lbs. Moment of Inertia 835 c. m

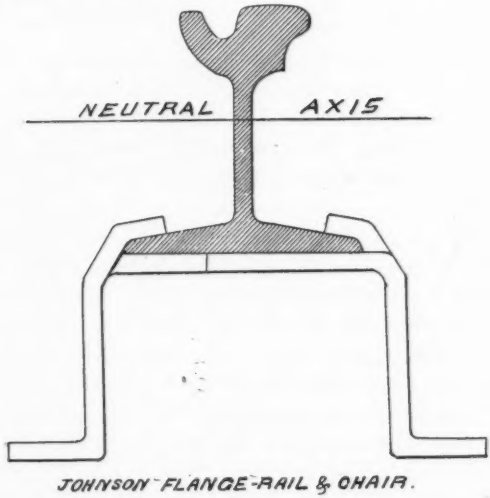


FIG. 16.

Weight per yard (rail only) 78 lbs. Moment of Inertia 1 603 c. m.

The tramways of Lille were laid with a twin rail having a cast-iron distance piece. The wearing rail being bull-headed, and the other a similar rail, but only having half a head, it acted like the guard rail on steam railways.

The Lewis & Fowler and the Gibbon rails are the two most recent forms of the box-rail.

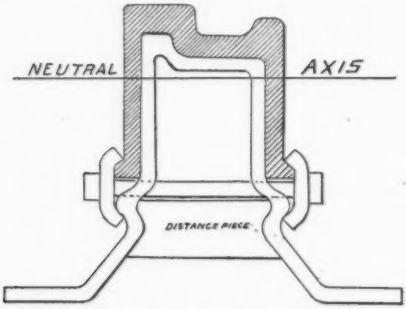


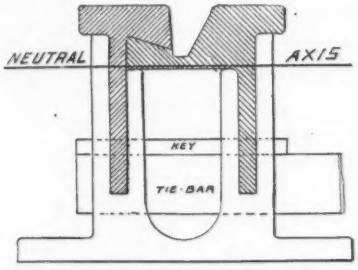
FIG. 17.

Weight per yard (rail only) 78 lbs. Moment of Inertia 1 227 c. m.

In the Lewis & Fowler rail (Fig. 17) the webs form part of the rail itself, consequently have greater strength than when divided.

In the Gibbon duplex rail (Fig. 18) one web supports the wearing head, and is removable. The other supports the tram. The attachment is by spring wedges, and without much disturbance of the pavement, the worn portion can be removed and a fresh one replaced. Here is a decided step in economy where there is not heavy vehicular traffic. It is proved, however, that in crowded thoroughfares subject to dray traffic, the entire rail surface wears equally, and the advantage of division in the rail would be little or nothing. Both rails have considerable stability of figure, and the Gibbon rail appears to be the only one which possesses an attachment without bolts. Both the Lewis & Fowler and the Gibbon attachments are excellent, the only drawback to them being, that some of the paving must be removed in order to get at them. Neither of these systems has any tension-flange to the rail, consequently the same criticism that was applied to the flangeless girder-rail is also applicable to them in greater or less measure; but when, as pointed out

at the commencement, from 90 to 95 per cent. of unworn girder-rail is doomed to the scrap heap, any device, such as the Gibbon, which can materially diminish this great waste deserves serious attention.



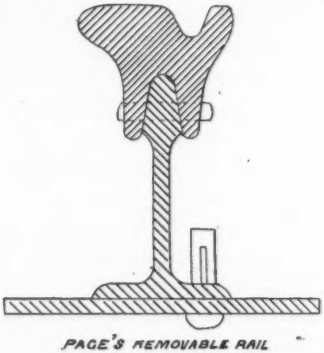
GIBBON'S DUPLEX GIRDER RAIL AND CHAIR

FIG. 18.

Weight per yard (rail only) 78 lbs. Moment of Inertia 811 c. m.

Both the Lewis & Fowler (Fig. 17) and the Gibbon system (Fig. 18), the former especially, give a good wall to the pavement which the girder-rail does not. The moment of inertia of the 78-pound Gibbon rail is 811 and that of the Lewis & Fowler 1 227 centimeters.*

The Page rail used on the North Metropolitan tramways in London is a further step in economy. It is a modification of the girder type, in



PAGE'S REMOVABLE RAIL

FIG. 19.

which the wearing head is removable, having a longitudinal recess or mortise into which the upper part of the web fits and is wedged up

* See discussion on this point.

with cotters. This attachment has the appearance of great weakness, but the principle might be conserved with a stronger attachment by deepening the recess sufficiently to admit of a double row of wedges which might be zigzagged.

Flat Rails.

The original type of flat rail consisted of a broad wearing head, with a shallow step, and a broad tram; it was rolled in sections weighing from 30 to 60 pounds per yard, and attached to the wooden stringer by spikes through the middle of the tram. In the heavier sections an attempt was made to lighten the head by hollowing it, but it was found that the rail worked its way into the timber.

When upon a continuous metallic support, the flat rail need not be much heavier than the amount of wear allowed for. That is to say, supposing the full wear of a rail to be ½-inch, the rail should be about ½-inch thick, so that by the time the car wheel begins to run on its flange there will still be about ½-inch left at the time of removal. The various modifications in the form of the head, such as side-bearing, etc., will be considered as part of the subject of rolling surface. Although every rail not provided with a vertical web is termed a flat rail, some of the types are anything but flat.

Economy of Renewal.

The aim of the street railway company for its own sake as well as that of the public, is to have a track which will wear well. Unfortunately, it has often to take in hand a contractor's line, one built on speculation, not by those who propose to work, but by those who desire to sell it at a large profit on their outlay. Consequently, whilst it may provide showy cars and perhaps electric motors, the track, being so much of it underground, is the least valuable part of the assets. Frequently a system, doing a large business and with good prospects, finds itself at the end of two or three years in a bankrupt condition because the whole of the roadbed requires renewal. A track which has cost $15 000 per mile, including paving, renewed at the end of three years, will cost sometimes $12 000 a mile, although the pavement is but little worn. The wooden cross-ties being decayed require the removing of the whole pavement, which with relaying, is equal to from a third to half the original cost of paving. In order to keep out of financial

trouble, a company possessing such a roadbed ought to write off from revenue a reserve fund of $4 000 per mile per annum, to meet a renewal at the end of three years.

No company, however, would care to confess to having a track of triennial periodicity, it therefore generally pays as good a dividend as possible out of all it earns, and hopes for some new revelation of electric science by which it will be able to reorganize like a butterfly from its chrysalis.

In the Mackison way with good rails and materials of foundation, the renewal say, at the end of seven years, of 1 mile would be, for

Rails	$2 531 20
Removing and refixing ditto, say	440 00
Total	$2 971 20

One-seventh of this amount would be $424, which would not be a large sum to write off revenue. It represents 3.13 per cent. of the first cost as against 33⅓ per cent. on the speculation system.

In the Shaw system the renewals would be:

Rails	$3 136 20
Removing and refixing ditto, say	440 00
Total	$3 576 20

One-seventh of this amount for yearly reserve fund would be $511 nearly, which represents 5.98 per cent. of the cost, with only longitudinal trenches of concrete, and 4.47 per cent. of the first cost with a complete concrete bed.

Street railways are in the main valuable and improving properties; easier to finance, quicker to yield a return, and more readily salable than larger railways. The speculative element is rapidly on the decrease, and promoters are coming to a sound cash basis as the best, and in the end most paying method, of organizing their enterprise. No prospectus which does not take renewals of track into account and show how they are to be met, ought to find acceptance with the investing public.

The question of renewals has another aspect. The general public is being continually tried in its proverbial patience, by needless interruptions of the traffic from the breaking up of the pavement in order to renew the track. The plain duty of municipal authorities is to see that the railway does not make its own interests unnecessarily conflict with those

of the community, but when once a cheap track is down, it has to be renewed constantly or the traffic must stop. The time for the municipality to act is when the concession is applied for. It would be perfectly fair for the authorities to stipulate for an inspector to be appointed by them at the expense of the company, who should see that the materials of construction were sound, and the work executed properly. There would then be less danger of old rails going down, as has been the case in some cities.

Rail Surfaces.

The question as to what is the best surface for a street railway track is not to be answered in a word. Numerous as are the designs which have been adopted in different countries, the chief considerations have been either on the part of the company to obtain a minimum resistance to traction, or immunity from the use of the track by other vehicles and a security from derailment; or else on the part of the city authorities to obtain a surface which will not obstruct the passage of any kind of vehicle across the track, or in some cases, and in direct conflict with the company's interests, to obtain a track which can and will be used by other vehicles, like the Deas rail already referred to.

The step-rail, whether as a single step in the form of side-bearing or double step in the form of center-bearing rails, continues to be the ruling type in America. The grooved rail was introduced into New York by M. Loubât in 1850, but its dimensions were so formidable that it was discarded, and the step-rail substituted—first in Philadelphia, and, until lately, throughout the United States, from the idea that the grooved rail was dangerous to wheel-tires, and because the railway companies preferred it.

In 1870 Mr. George Francis Train introduced the tramway to England with a step-rail. It gave such offense, that after losing his London concessions, he only saved those at Birkenhead by taking up the track and relaying with a grooved rail.

The groove in any form requires more cleaning than the step-rail, but as against this fact, it suffers less wear from passing vehicles. This is evident from the sight of heavy drays in their attempts to free themselves from the rail, scraping along its side for a considerable distance before they can mount it.

The wearing head of the center-bearing rail was made of a small radius to prevent wagons from riding on it, and this might also be done

with the grooved rail. As a matter of fact, when the streets are well paved, vehicles do not use the car track, but rather avoid it.

The latest cable roads in San Francisco have been made of 3-foot gauge, which not only gives less paving for the company to keep up, but also effectually keeps off vehicles. On this gauge, cars are perfectly stable when built of the same width as those of 4-foot 8½-inch gauge, even when traversing curves of 30 feet radius, if slowed down to 4 miles per hour.

The advantages of interchange of gauge is not of the same importance as on large railways. A line which does a good business does not want foreign cars to have running powers over it, neither is there much to be gained by bringing freight cars from steam railroads along the line at night, except for hauling coal to a power station.

Where streets are paved there is nearly always enough traffic to pay for a frequent service of cars. Grooves do not clog up much, and the busier the thoroughfare the more greasy is the mud which gets in them. Under those conditions it is fair to lay upon a company the small cost of groove cleansing.

On macadamized roads, even where the track itself is paved, the traffic is generally lighter and the roads are dustier. The dirt is always gritty, and produces much flange friction on the car wheels running in grooves.

In England tramway companies are compelled to use grooves on all roads, but it seems an unreasonable demand, when by laying the track on the side of the road a clear drive-way is afforded the public, and the inconvenience of crossing a step-rail almost entirely avoided.

The possible trouble from a frozen groove is one which it is difficult to estimate except from actual data, but in most cases, even in the coldest climates, it is liable to be exaggerated. If a dead level track froze hard after a fall of rain without any traffic upon it, it would require picking out with a hammer and cold chisel, but tracks have nearly always sufficient grade to pass the water off, and, as a matter of fact, one never does see a groove standing full of water. If only half-full, the car-wheel will run on its flange smoothly until it breaks the ice, and then run on the tread as usual.

General Conclusions.

First.—The wear upon the rail-head due to vehicular traffic combined

with that of the cars is very great as compared with steam railways, and different in its character. The rail is worn down by mere abrasion, long before either the shank or the lower flange has succumbed to fatigue or crystallization from the transverse stresses developed in them by the passing loads. Consequently economy calls loudly for a divorce between the head and lower member, or rather that they should remain together in a union which does not demand their simultaneous descent into the scrap heap.

Second.—The steel best adapted to resist attrition, has a larger percentage of carbon than the ordinary mild steel used in rail or girder construction.

Steel rails are now made with a higher percentage of carbon in America than in England. According to Mr. Sandberg, quoted by Mr. Tratman in his paper, they contain 0.50 to 0.60 per cent., special attention being devoted to hot pressing in the mills to avoid risk of fracture.

If, however, the rail-head were continuously supported and delivered from all transverse stresses, it might contain as great a percentage of carbon as would give it nearly the hardness of file steel, somewhere in the neighborhood of 1 per cent. A greater percentage of silicon might be permitted. Tungsten or chrome steel would be very suitable, and the specifications and tests for steel rails would be essentially different from those for steam railways.

Third.—The stringer, or longitudinal sleeper carrying the rail, should, if the ground underneath be solid, rest upon a concrete bed, and be so filled with the concrete as to obtain the supporting power of the concrete, and reduce the quantity of metal in the stringer to a minimum. Stringers made heavy enough to remain stable by their own inertia, or even including the weight of contained concrete, have but a small fraction of the stability obtained by using the tensile strength of the concrete itself in a properly bonded mass. Such systems endeavor to obtain, by the use of an expensive material, what they might do by a cheap one and fail to do it.

Fourth.—When intermittent supports are preferable, as upon the brackets of cable-yokes, or when the ground is weak and concrete would be liable to settlement, the stringer should be a girder of such a form that the material for resisting torsional and transverse stresses will be distributed in the most effectual manner—that is to say, material

should not be put into the web to obtain stability, but only to resist shearing. The upper and lower members of the girder, should be proportioned to the longitudinal stresses of tension and compression, according to the respective strengths of the material in each of those particulars. The stability or resistance to torsion should be inherent in the geometric figure of the girder, and not from an otherwise unnecessary thickness of the web. It should certainly not be dependent upon any agglomeration of bolting or riveting such as the high chairs, which have been well nick-named stilts, which may or may not be properly constructed, and upon which the same comment may be made as Dr. Johnson remarked upon the bear walking on its hind legs: "Very ingenious, but why should he do it?"

The elasticity of the track has already been touched upon, and it will suffice to remark, in summing up the matter, that the future of city transit will not probably produce much change in the conditions of roadbed. Motors will not probably be heavier than the storage battery car of to-day, and the speed will not exceed the limits prescribed by city authorities for security to the lives of foot-passengers; consequently there will be no advance in the demand for elasticity in the city proper. There is likely, however, to be a great extension of electric lines into distant suburbs and adjacent towns, where the speed will vary from an 8-mile limit in the residential and business quarters, up to 20 miles upon the country roads. The type of construction would naturally require to be different, varying from a heavy imperishable and expensive roadbed, to the cheapest form of track which would properly carry the motor cars.

Fifth.—The sides of the stringer should be vertical to form a support to the paving blocks, and of sufficient depth to allow about an inch of sand between the bottom of the blocks and the concrete bed or metallic cross-ties, as the case may be.

Sixth.—No perishable material should be used in any part of the construction. As pointed out in Mr. Tratman's paper, the tendency of the steam railways is towards an all-metal construction, the first step being the use of bearing plates between rail and tie. The attention of the Department of Agriculture is being particularly drawn to the rapid denuding of the forests, and the attention of the railway companies is being drawn to the increased cost of lumber. It is probable that before long the question of steel rail supports for steam railways, either trans-

verse or longitudinal, will be answered by the introduction of an all-metal system, which will compete as to price, whilst it will vastly exceed in efficiency, the composite system of to-day.

Eagerness to obtain traveling facilities to assist rural development, still leads municipal authorities to permit the construction of cheap and perishable tracks, which in the course of a few years will have to be renewed, involving the removal of pavement and serious interruptions to the traffic and business of the streets.

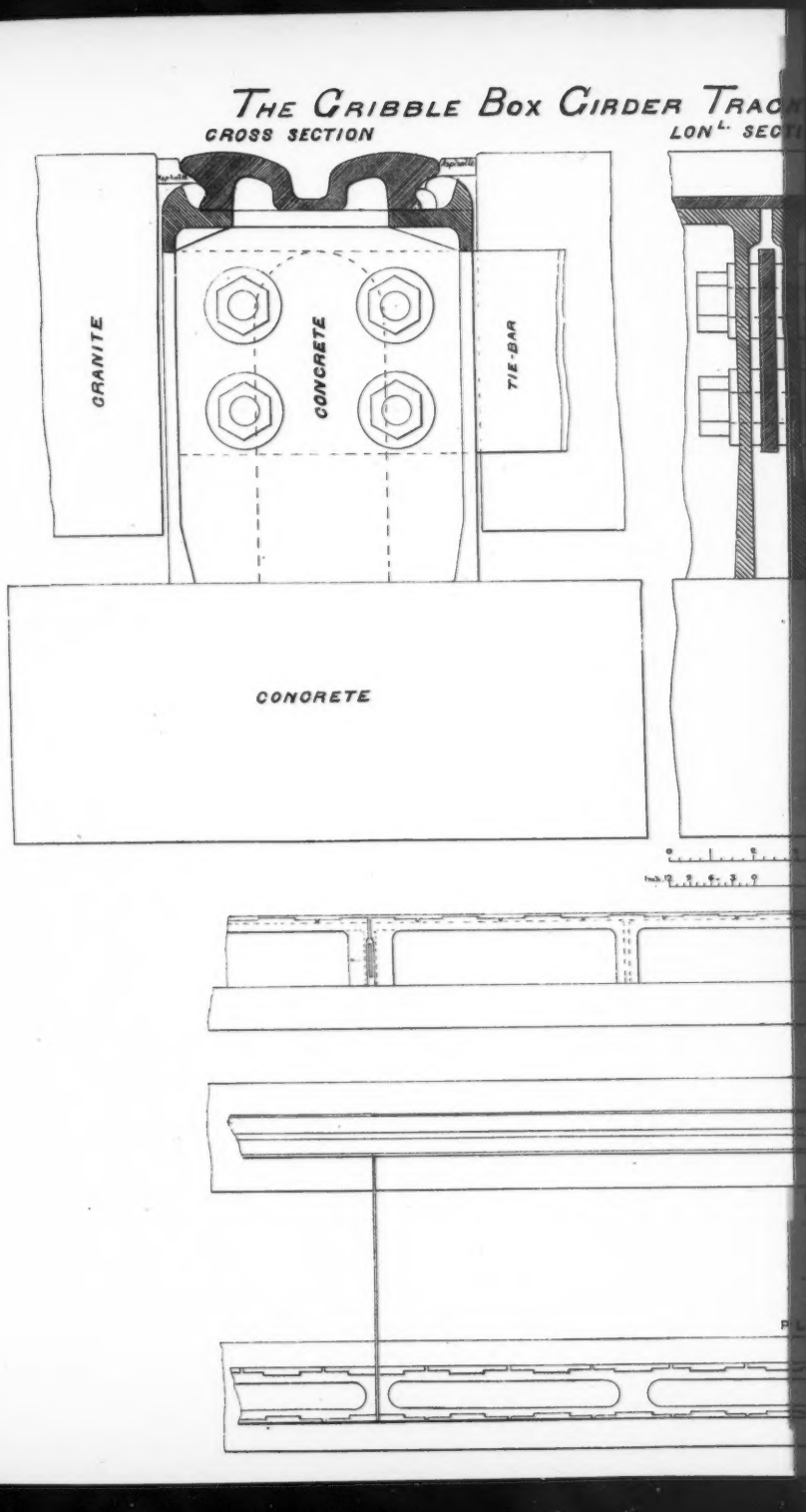
Companies are open to the charge of having in many cases laid down a roadbed unequal to the business which they contemplated, without taking into account the strides that have been made by mechanical traction. They are now, however, adopting for their own sakes a much more durable type of construction. To sum up this point:

Municipalities should demand, intending investors should stipulate, and companies should for their own sakes specify, that not a particle of timber should enter into the construction of street railways under any kind of pavement, whether granite, asphalt or Nicholson. In macadamized roads it is also bad policy to use timber, but in graveled country roads, with light traffic, it is a question of that or nothing, and the track, placed on the side of road, can be renewed without much interruption of the traffic.

Seventh.—The attachment of the rail, which should be removable, should be accessible without disturbing the pavement. Several types of rail already described more or less fulfill this condition, and the points to aim at are as follows: To be able to replace the rail whilst the cars are running; to avoid piercing the rail or any kind of machining upon it; to apply the fastening in such a manner that the points of attachment will be external to the point of application of the load, and consequently not be subject to torsional stress.

Eighth.—A rail surface flush with the road outside and inside the track is only obtained by the grooved rail. It is, in paved streets, economical to the company, having regard to renewals, and both safe and convenient to the general public. On country roads, graveled or macadamized, a step-rail is greatly to be preferred by the company, and is permissible by the authorities. The track should, however, be laid on the side of the road.

Ninth.—The present gauge of 4 feet 8½ inches is unnecessary for stability of cars, and the 3-foot gauge, now being adopted in California,


THE GRIBBLE BOX GIRDER TRAC
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ER TRACK SYSTEM A WITH CAST STRINGER.

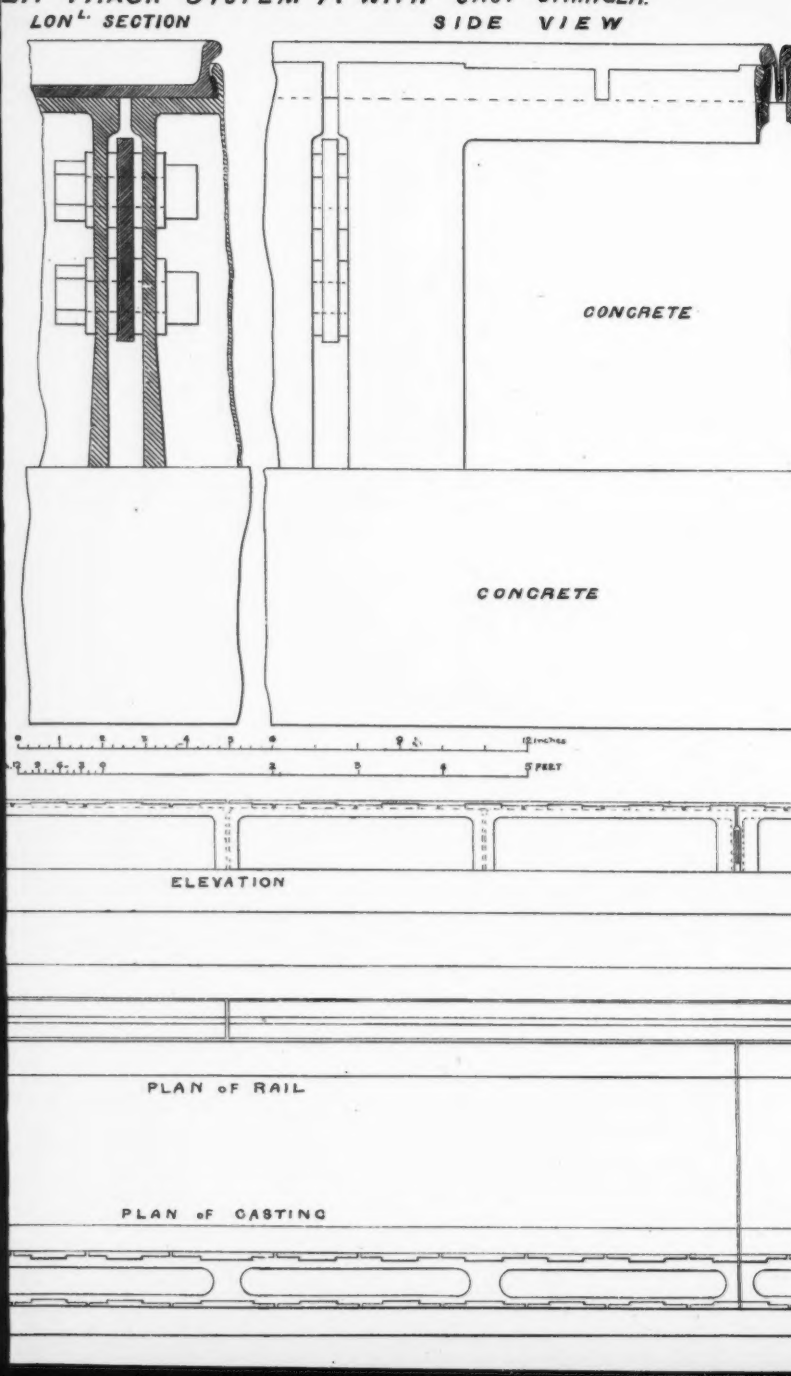
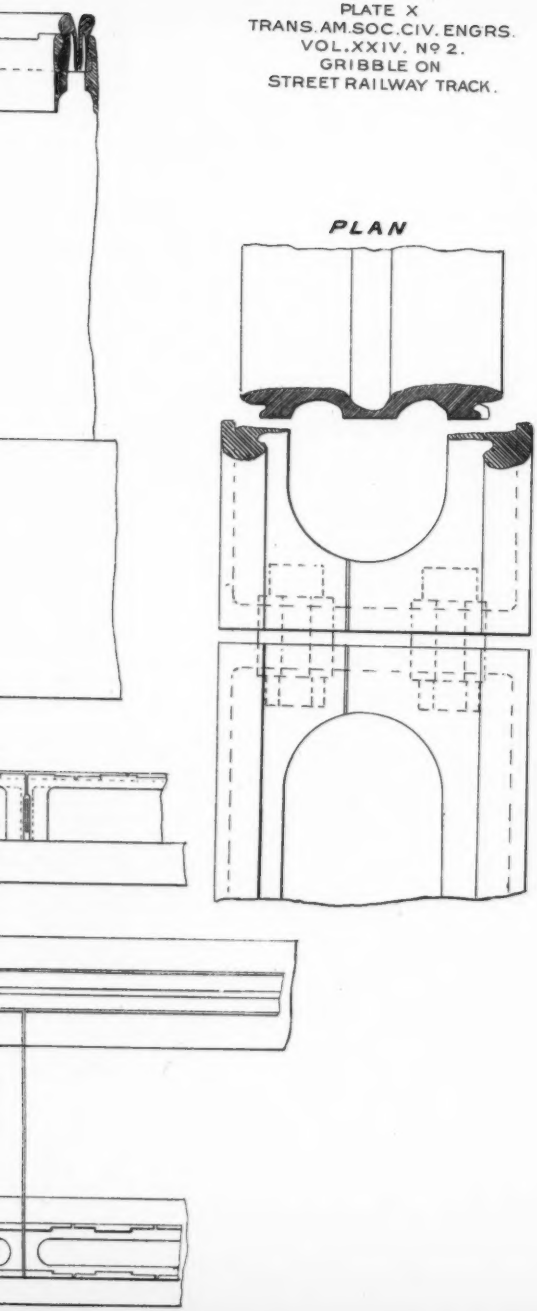


PLATE X
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXIV. Nº 2.
GRIBBLE ON
STREET RAILWAY TRACK.



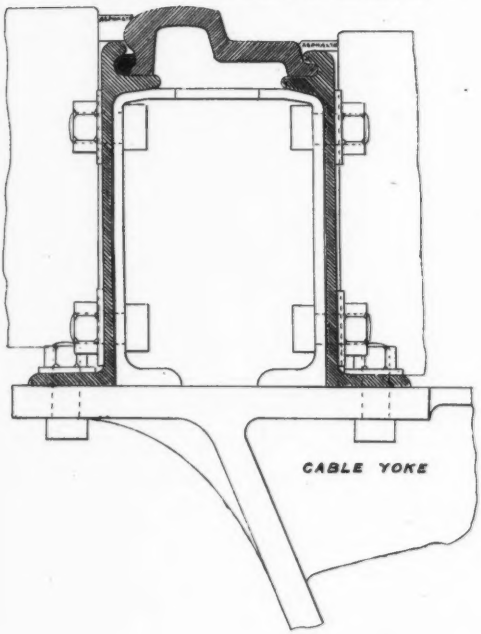
THE GRIBBLE

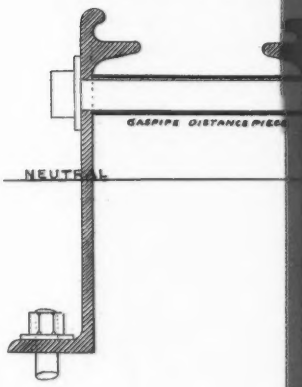
SYSTEM B. WITH

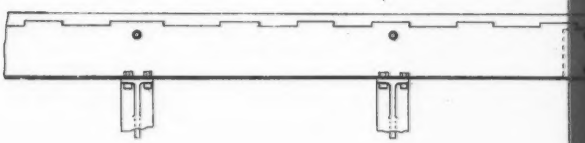
FOR CABLE ROAD

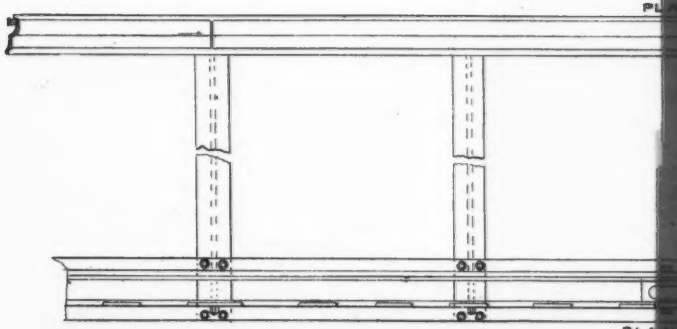
CROSS SECTION OF STRIN

CROSS SECTION AT JOINT SHEWING SPLICE CASTING







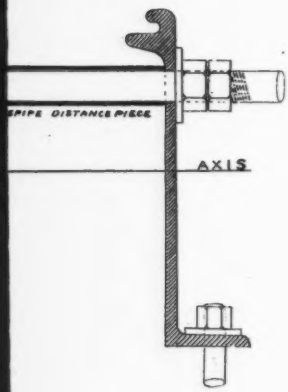


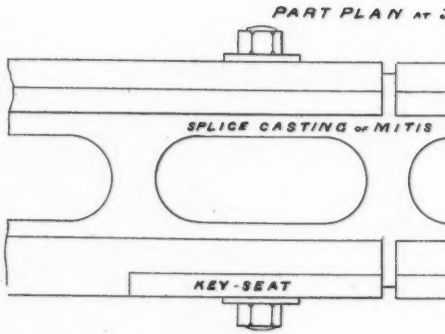
GRIBBLE BOX GIRDER TRACK

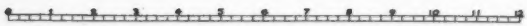
M B. WITH ROLLED BEAM STRINGER

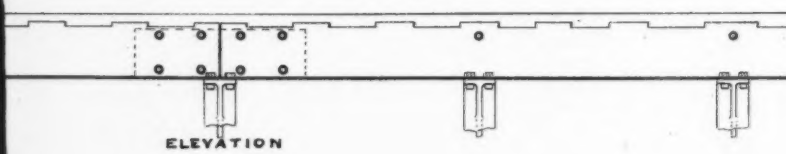
FOR CABLE ROADS OR ON METAL CROSSTIES

TION OF STRINGER









PLAN OF RAIL

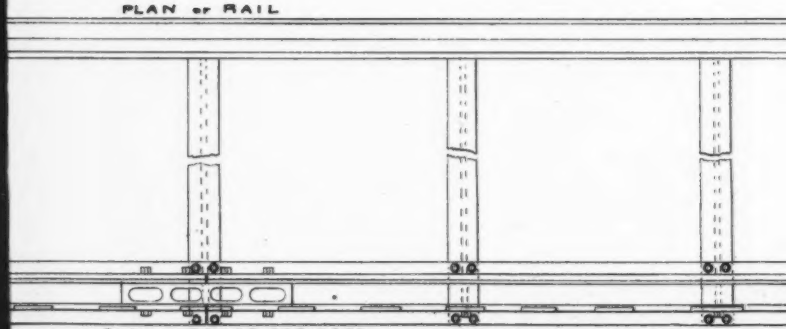
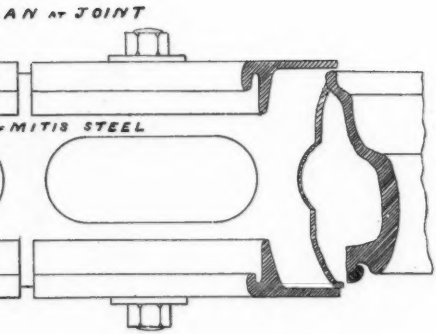


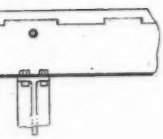
PLATE XI
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXIV. Nº 2.
GRIBBLE ON
STREET RAILWAY TRACK.

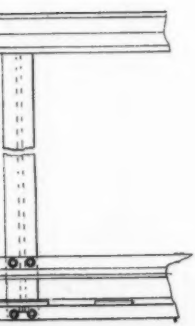


WEIGHT PER YARD.

RAIL,	22 Lbs.
GIRDER,	56 "
TOTAL,	78 "

MOMENT OF INERTIA (ex rail) 2060 c. m.





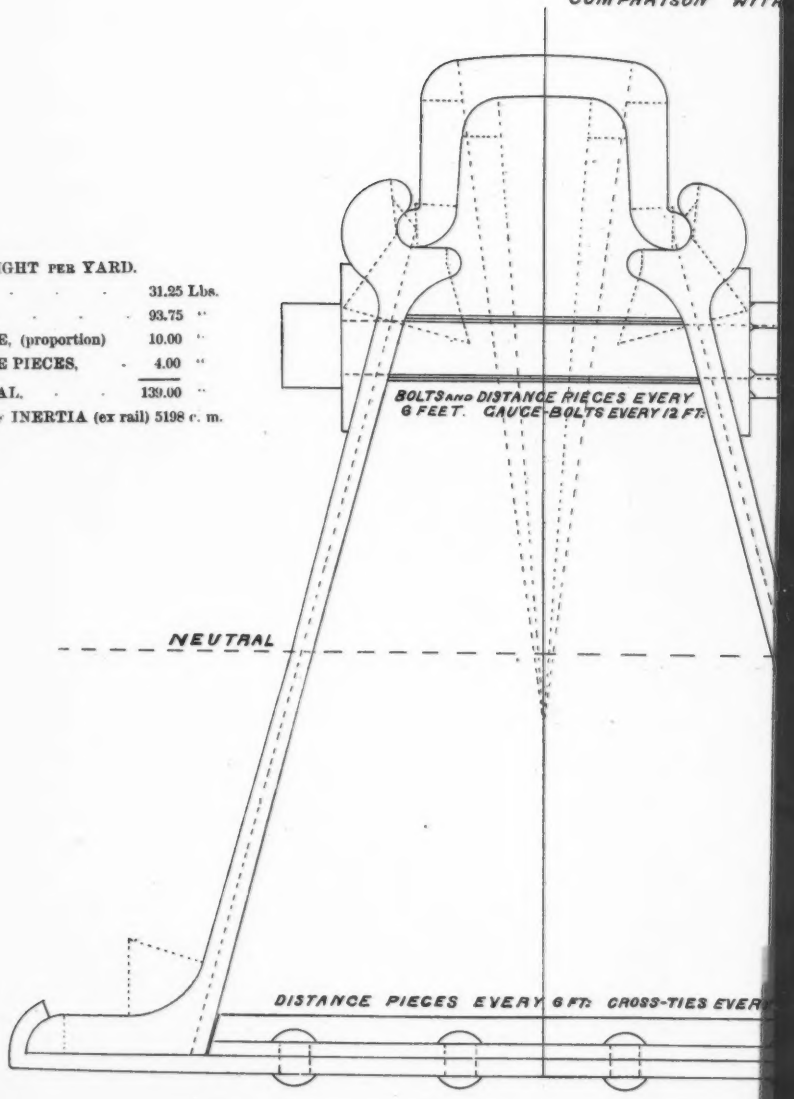
THE GRIBB

SYSTEM C. ATTA

COMPARISON WITH

WEIGHT PER YARD.	
RAIL,	31.25 Lbs.
GIRDER,	93.75 "
CROSS TIE, (proportion)	10.00 "
DISTANCE PIECES,	4.00 "
TOTAL,	139.00 "

MOMENT OF INERTIA (ex rail) 5198 c. m.



GRIBBLE BOX GIRDER TRACK

C. ATTACHMENT WITHOUT WEDGES.

ISON WITH SANDBERG'S GOLIATH RAIL

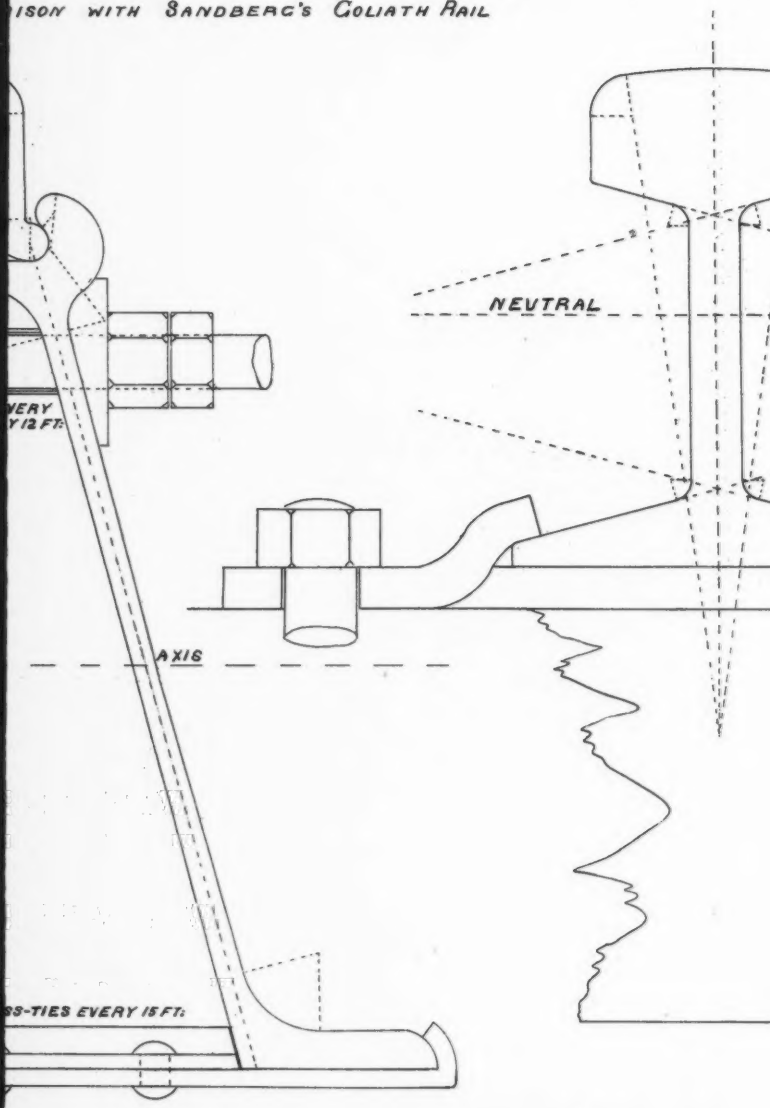
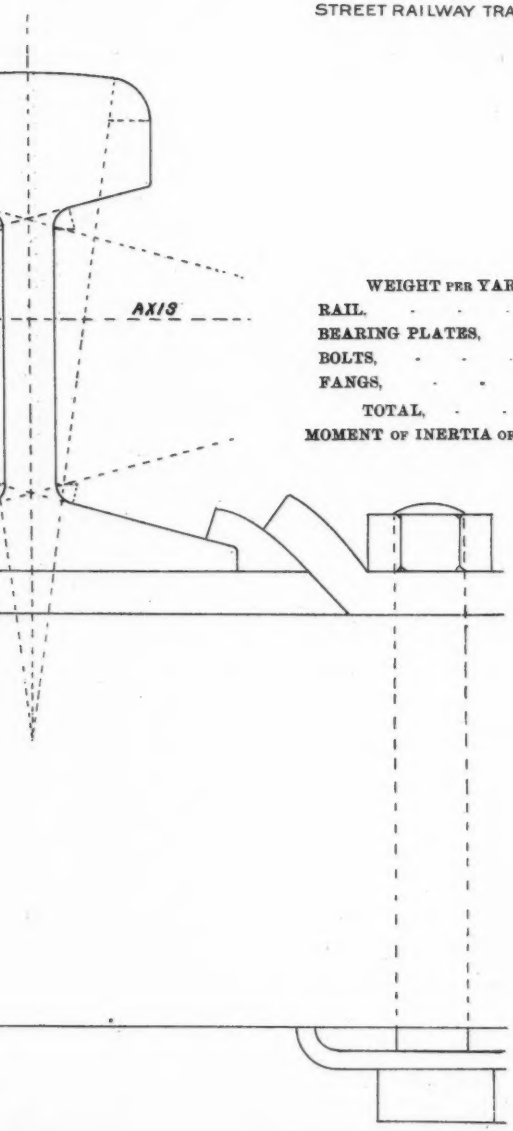


PLATE XII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXIV. Nº 2.
GRIBBLE ON
STREET RAILWAY TRACK.



WEIGHT PER YARD.

RAIL,	100.00 Lbs.
BEARING PLATES,	19.20 "
BOLTS,	15.10 "
FANGS,	4.21 "
TOTAL,	138.51 "

MOMENT OF INERTIA OF RAIL 1932 c. m.

is preferable, not only for economy in paving, but also for preventing the use of the track by foreign vehicles.

Box Girder Track Suggested by the Author.

Plates X, XI and XII, are explanatory of the way in which the author has attempted to embody the views above expressed. The use of metallic keys is not a novelty, but the arrangement of them in a continuous series has been adopted in order to preclude all liability to working loose, and to provide a strength greatly in excess of any stress that can be estimated upon them. Considering the lugs under three forms of stress, vertical, horizontal or intermediate, whether in direct shearing or transverse strain, it would require a force of over 100 tons to remove the rail from one 12-foot box.

The protection of the lugs by a covering of sand and asphalt was suggested by the experience at Honolulu with the grooved rail shown on Fig. 4. The space is in no case as much as an inch, so that nothing but a very light buggy wheel could come on it. In macadamized or graveled roads a single longitudinal row of granite paving blocks should be laid on each side. The method of construction would be to lay the longitudinal bed of bottom concrete first, and then align one casting from the surveyor's center line. On the cast stringer there is a nick marking the gauge line. The casting, 12 feet long, can be lifted easily by two men, and can be aligned and leveled in a few minutes, so that the bottom bed will not have begun to set during the process; side boards are then placed to retain the concrete filling, which is introduced from the opening at the top by means of funnels, and packed close up to the sides by bent irons. The concrete is then allowed to set, the side boards removed, and the upper surface rendered in cement mortar flush with the metal. The second line of stringers is aligned from the first by gauge-bars. Tie-bars are shown on the drawing. They will be only required for curves, and it is doubtful if they will be wanted there. The keys will be driven or removed by a bent steel die, terminating in a shank fitting into a striking piece separate from it. The keys themselves will be of lead, or mitis casting, or possibly oak. For the lug holding the rail-joint a key of lead would be preferable, because the ends of the rails, not being perfectly similar, would obstruct its passage less. The lugs will have a slight taper, and when the key is driven it will be slightly upset, or clinched by striking it at both ends simultaneously. The lug over the joint is made

longer than the others. There will be much more bearing surface on the keys than on the key of Mr. Sandberg's Goliath rail, illustrated in Mr. Tratman's paper, although subjected to much less shock.

The rail will be inserted or removed sideways. Frogs and switches will also be reduced to nothing more than a wearing surface removable in similar manner, resting whether in system *A* or *B* upon a casting. If in system *A*, the casting will be filled with concrete, but if in system *B*, it will be furnished with bottom flanges and bolted to metallic cross-ties.

Comparisons of cost are difficult to make, when the cost of single track under present systems varies from $6 000 to $30 000 per mile according to circumstances. Such statements are, moreover, generally received with much reservation as to possible exaggeration in favor of the promoters' own ideas. It is preferable to compare quantities of material, and for the sake of illustration, a girder-rail system with a 78-pound rail mounted on a steel chair attached to a chestnut cross-tie, will be compared with proposed systems *A* and *B*. The prices adopted by the author for his own estimates give with steel at 2 cents per pound, cast-iron at 2 cents per pound, and concrete at 25 cents per cubic foot, a slight advantage to the girder-rail; whilst with prices at 2 cents for steel, 1¼ cents for cast-iron, and 20 cents for concrete, the advantage would be somewhat the other way. A 12-foot casting weighs from 120 pounds upwards = 30 pounds per yard. The rail from 20 pounds per yard. The weight of metal is, therefore, about the same as in the girder-rail with chairs.

The renewal would be about one-fifteenth part of that of the girder system when laid with timber cross-ties, allowing a life of seven years to the wearing head of the girder-rail and then the renewal of all things. In the author's system there might be a life of fourteen years to the wearing head, due to increased hardness of the material, without taking into account the reversing of the rail, which would also have its value. In the end of that time there would only be a weight of about 25 pounds per yard of renewal, the stringer remaining as permanent as the foundations of a house or the bed-plate of an engine.

System *B*, with Rolled Stringer.

In this case, see Plate II, the material has been arranged to combine vertical sides, a broad base, and a symmetrical arrangement of tension

and compression members. Following up the comparison of different rails previously given, the system *B* stringer would have a moment of inertia of 2 060 c. m., for a 78-pound section, and the cost of renewal would be only that of the wearing head.

Joints.

In the system with cast stringers and concrete, the expansion upon one 12-foot casting due to 100 degrees Fahr. would be 0.089 inch; the expansion of the concrete, assuming it at one part in 100 000 per degree Fahr., would be 0.144 inch. The difference of 0.055 inch would not exceed the elastic limit of good cast-iron if produced as an extension upon it by the concrete, but a cushion of sand will be left at the end of the castings to take up this expansion, and washers of split steel used between the two castings to permit the metal to expand.

At every 24 feet a half-inch board will be placed so as to form a division in the lower concrete, and withdrawn when the latter has set.

In the systems with rolled stringers, the joint is formed by a saddle-casting forming an internal support to both the upper surfaces and sides of the beams, its depth permitting the use of bolts with great leverage of resistance to deflection.

The casting will be furnished with openings for bolting, and the whole stringer will be filled with ballast before the rail is laid on.

System *C*.

Though scarcely within the range of the subject of this paper, a brief comparison will be made between the box-girder principle applied to the Goliath 100-pound rail of Mr. Sandberg. The principle holds good for lighter rails down to a 50-pound section, and as street railways running into suburbs often use flanged tee-rails, it may be as well to complete the description of the box-girder system with its application to any kind of heavier railway.

The moment of inertia of the Sandberg rail is 1 932 centimeters. Comparing it first of all with the 78-pound street railway girder-rail, illustrated, Fig. 16, whose moment of inertia is 1 603 centimeters, it will be noticed: 1st, That the shank is much wider in the Goliath, and the flanges deeper at the throat. In the street rail the material is massed at the extremities, so that it has the same depth as the Goliath and a wider bottom flange. Consequently, although it has

only 78 per cent. of the area, it has 83 per cent. of the moment of inertia. Recollecting that moments of inertia of similar figures vary as the squares of their respective areas, the girder-rail shows a very much stiffer figure than the Goliath. This is no reflection upon the Goliath, because the two rails are in very different lines of business. The Goliath needs an elephantine trunk to stand the torsional stresses of heavy locomotives. Both are well designed for their duties.

Next, comparing the Goliath with the box-girder, system *C*, we find very remarkable results. In the latter, in order to give it a sufficient base for supporting the rail as a longitudinal stringer with only an occasional cross-tie, the equivalent weight per yard of rail has been substituted for the Sandberg bearing plates, fangs and bolts.

	Pounds. Per yard forward.
Wearing head	31.25
Box-girder stringer	93.75
Cross-tie, every 15 feet	10.00
Distance pieces and gauge bars	4.00
Total steel per yard run	139.00

The stability of figure is 1, as against 0.833 in the Goliath. That is to say the box-girder has 20 per cent. more stability, although it has twice the depth. The moment of inertia is 5 198 centimeters, or 169 per cent. more than the Goliath.

Placed side by side on bearings 10 meters apart the deflection of the Goliath under a uniform load of 5 tonnes* per meter would be 4.95 centimeters. The deflection of the box-girder would be 1.84 centimeters.

The strength is increased by 62.2 per cent. The Goliath rail would be safe under a load of 5 tonnes per meter on a span of 3.10 meters, *i. e.*, with 15.5 tonnes upon it. The box-girder would be safe on a span of 4.00 meters with a load of 5 tonnes per meter, *i. e.*, with 20 tonnes upon it, uniformly distributed; ordinary 12-foot culverts would be spanned by the box-girder without any assistance, and by rolling the beams 12 inches deep, making the total depth 15 inches, small bridges of 15 to 18 feet could be spanned by it.

The rail is designed to be under compression alone, and is in effect a pivoted arch, having an articulated line of thrust which passes

* French tonnes of 1 000 kilogrammes.

directly down the center of the rolled beams. These are very thin at the center, being supported from buckling by the filling within and the ballast without. If used to span culverts they would either be rolled thicker or have stiffeners. They are held together by a light distance piece every 6 feet, and a steel cross-tie every 15 feet, the latter not for bearing surface but to keep the beams out of winding. They are held at top and hold the rail by a $\frac{3}{4}$-inch bolt every 6 feet, which at every alternate point, that is at every 12 feet, terminate in right and left-handed screws to receive a gauge-bar with turnbuckle.

A freedom is allowed in the lower fastening to admit a movement in the jaws of $\frac{3}{16}$ of an inch for inserting the rail, and lock-nuts are provided for keeping it tight.

Before inserting the rail the box will be filled with loam, sand or peat, and the rail also filled bottom up, so that when in place the girder in settling down to its bearing on the ballast will leave a cushion for the ballast to work up into, and so diminish vibration; in addition to this some strips of tarred felt will be placed between the rail and the jaws. It is submitted that by this method 80 per cent. of the track would be constituted an asset of the company, subject to no greater depreciation than the bridges or station buildings; furthermore, that the rail could be safely composed of a steel which would outlast two of the present mild type; last, but not least, that there would be no danger of accident from broken rails, and this at the same initial cost.

The Crossing of Larger Railways by Street Railways.

The state of the law in America regarding this matter, appears to be that the railway company having the priority of right, is not only entitled to compensation in respect of any interference with its adjacent roadbed; to payment for extra supervision of the crossing as a precaution against accidents, but also to entire immunity from interference with its rail-surface by the tramway.

The mode of procedure is generally as follows:

The street railway gives notice of its intention to cross the larger railway, and is received with diplomatic reserve.

The street railway then proceeds to lay its track up to and between the rails of its great-cousin, and is received with a club.

Litigation follows, terms are agreed upon, and finally the street car is permitted, for a consideration, to come up to, jump over the heavier rail, and wend its way in peace.

The temper of the steel car-springs and that of the passengers inside is equally tried by the process, but with characteristic patience, and thinking probably that it is to save accidents, the latter make no objection.

If the cutting of the rails of the steam railway were necessarily attended with danger, it would be imperative that the street car should mount the other rail, whatever the inconvenience; but since, in a very great number of cases steam railway cars cross one another's lines on the level by cutting the track, that is to say, by putting in square frogs, this argument has no force. There must be considerably less chance of derailment of a car on such a crossing than when jumping over the larger rail upon its flange.

The priority of position on the part of the larger railway, is the foundation of its claim. It has been granted a right of way by the State, and demands to keep it without any interference. But there is a broader view of the question, which is coming more and more to the front all over this continent. The proper place for high-speed trains is not upon the surface of the highways. A steam dummy going at 10 miles an hour is bad enough, but the passage of a rushing train across crowded thoroughfares, will soon be generally looked upon as a reckless disregard of human life, unworthy of a paternal government.

The street car in whatever manner operated, but regulated by local supervision, is the right thing in the right place, but the locomotive, whatever its right of way, is destined to be put somewhere out of the way of pedestrians. As long, then, as it remains where it is by public sufferance, it may be fairly called upon to diminish its speed and cross the street car line by a similar crossing to that which would be put in for crossing another steam railway, and there seems no reason why a general statute should not be framed, which would adjust compensations so as to avoid litigation in all ordinary cases. Being a matter of public safety and convenience, it would be as appropriately treated by legislation, even down to the form which the crossing should take, as the matter of signals, platforms, or other points of railway construction which are subject to Government rules and inspection.

Curves.

The use of parabolic or transition curves, is becoming imperative upon street railways. The radii cannot be increased, but the speed is

constantly being accelerated by the introduction of mechanical traction. The company protects its cars from derailment upon sharp curves by means of guard rails, but cannot prevent its passengers from the unpleasant swing and jolt when the cars turn a corner, nor can it avoid the wear and tear to the car wheels and axles from the sudden cross strain.

It is noticed by locomotive superintendents, that the wear of tires on single-line railways with frequent crossing stations, is more on one side than the other, although the right and left-handed curvatures may be equal. This arises from the fact that trains enter crossing stations quicker than they leave them, and wear the running gear on the side on which they strike the facing points.

Formerly switches of street railways were operated by the driver, and the car was almost at a standstill. Very sharp switches were made to economize length, and the horses helped the car round. Now, with higher speeds and switches worked either automatically or by a switchman, it is advisable to have them nearly as long as those on steam railways, so that the car may traverse them with undiminished speed.

The parabola is the curve which gives a uniformly accelerated resistance to rotation, and is sometimes put in by ordinates from tables, but it is not a convenient figure for calculation or for combination with circular curves. Mr. Searles in his "Railroad Spiral," uses a combination of circular curves, which is in alignment sensibly a cubic parabola, but has the advantage of being readily calculated from the properties of the circle, and still more readily laid off upon the ground. He uses a basic angle of ten minutes, by which he uniformly increases the curvature. The chord may be anything, but the increment of curvature and total curvature from commencement, are the same for any point in the spiral. Thus, whether with a chord of 2 feet or 100 feet, the total curvature at the first point is ten, at the second point twenty minutes, and so on. In the author's book on "Preliminary Survey," recently published, a series of tables has been arranged for decimal degrees, which simplify the calculation, and the basic angle is 0.2 degrees; that is to say, twelve minutes. A book of trigonometrical functions for decimal notation, by Dr. Bremiker, of Berlin, may be procured at trifling cost from Messrs. Keuffel & Esser, of New York City. It is the original notation of Briggs, in 1633, followed by Oughtred, in the hopes of getting rid of the senseless sexagesimal subdivision which has, how-

ever, survived in triumph. Instruments can be adapted to the decimal subdivision by merely altering the vernier. The spiral may be applied in complete form to take the place of a circular arc or else only as a transition into a circular arc. Even upon the sharpest curves the combination of a pair of spirals with a circular connecting or "crowning" curve, occupies very nearly the same ground as a plain curve, the difference consists in, firstly, an earlier commencement of the curvature; secondly, a slightly sharpened curvature at the crown; thirdly, a somewhat greater clearance of the crown from the sidewalk.

Table A gives the general elements of the decimal spiral. Table B gives the co-ordinates of a spiral, with a chord of two units. When taken as feet it becomes a very suitable spiral for street railways. Table C gives the co-ordinate of a parallel spiral 4.75 feet beyond B. Taken at 4 feet 9 inches, it is suitable for the outside rail on standard gauge.

The following are the most simple problems for which formulas are required:

Problem I.

Given the co-ordinates x, y of a point in a spiral, the total curvature $\triangle$ or half-curvature Θ, and the radius of a desired crowning curve; to find the point of spiral or distance, $I\,S$, from the point of intersection of the main tangents to the point of commencement of the spiral, also the apex distance $A\,I$, or distance from intersection of main tangents to crown of curve.

$$I\,S = y + \text{tan. } \Theta\,(R \text{ cos. } s + x) - R \text{ sin. } s.$$

$$A\,I = \frac{R \text{ cos. } s + x}{\text{cos. } \Theta} - R.$$

Example.—It is desired to put in a spiral having a total curvature of 90 degrees, the spiral proper being carried up to point 13, and from thence a crowning or connecting curve of 40.93 feet radius:

$I\,S = 25.73 + \text{tan. } 45 \text{ degrees } (40.93 \times \text{cos. } 18.2 \text{ degrees} + 2.84) -, 40.93 \text{ sin. } 18.2 \text{ degrees} = 54.67.$

$$A\,I = \frac{40.93 \text{ cos. } 18.2 \text{ degrees} + 2.84}{\text{cos. } 45 \text{ degrees.}} - 40.93 = 18.07.$$

TABLE A.

General Elements of the Decimal Spiral.

No. of Point. n.	Curvature in one chord. nc. Degrees.	Total Curvature up to n. s. Degrees.	Total Curvature up to mid-chord or deflection of short chord from main tangent. k. Degrees.	Tangential angle or angle between long chord and main tangent. t. Degrees.
1	0.2	0.2	0.1	0.1
2	0.4	0.6	0.4	0.25
3	0.6	1.2	0.9	0.47
4	0.8	2.0	1.6	0.75
5	1.0	3.0	2.5	1.10
6	1.2	4.2	3.6	1.52
7	1.4	5.6	4.9	2.00
8	1.6	7.2	6.4	2.55
9	1.8	9.0	8.1	3.17
10	2.0	11.0	10.0	3.85
11	2.2	13.2	12.1	4.60
12	2.4	15.6	14.4	5.41
13	2.6	18.2	16.9	6.30
14	2.8	21.0	19.6	7.24
15	3.0	24.0	22.5	8.26
16	3.2	27.2	25.6	9.33
17	3.4	30.6	28.9	10.48
18	3.6	34.2	32.4	11.68
19	3.8	38.0	36.1	12.95
20	4.0	42.0	40.0	14.29
21	4.2	46.2	44.1	15.69

Problem 2.

Given the apex distance, total curvature and co-ordinates x, y of a point in the spiral to find the radius of crowning curve, and commencement of spiral.

Here it is necessary to find two auxiliary angles λ and μ from the given ones, Θ and S:

$\lambda = 90$ degrees $- \frac{1}{2}(\Theta + s)$ and $\mu = 90$ degrees $- \frac{1}{2}(\Theta - s)$ and as a check; $\lambda + \mu + \Theta = 180$ degrees.

$$R = \frac{A\,I \cos.\ \Theta - x.}{2 \cos.\ \lambda \cos.\ \mu.}$$

$$I\,S = y + \tan.\ \lambda\,[(A\,I \cos.\ \Theta) - x] + A\,I \sin.\ \Theta.$$

Example.—Total curvature, 90 degrees. Apex distance, 16.40 feet. Spiral, 22 feet long, *i. e.*, to end at point 11:

$\lambda = 60.9$ degrees; $\mu = 74.1$ degrees. $\Theta = 45$ degrees. $x = 1.759$ feet $y = 21.878$.

$$R = \frac{16.40 \times \text{cos. } 45 \text{ degrees} - 1.76}{2 \text{ cos. } 60.9 \text{ degrees} \times \text{cos. } 74.1 \text{ degrees.}} = 36.93 \text{ feet.}$$

TABLE B.

ELEMENTS OF STREET RAILWAY SPIRAL WITH CHORDS OF TWO UNITS. Plate IV.

n.	Radius. r.	Co-ordinate at right angles to tangent. x.	Co-ordinate in line of tangent. y.	Length of curve. l.
1	572.96	0.003	2.000	2
2	286.48	0.017	4.000	4
3	190.99	0.049	6.000	6
4	143.24	0 105	8.000	8
5	114.59	0.192	9.999	10
6	95.49	0.318	11.993	12
7	81.85	0.488	13.986	14
8	71.62	0.711	15.973	16
9	63.66	0.993	17.953	18
10	57.30	1.340	19.923	20
11	52.09	1.759	21.878	22
12	47.75	2.257	23.816	24
13	44.08	2.838	25.729	26
14	40.93	3.509	27.613	28
15	38.20	4.274	29.461	30
16	35.81	5.139	31.265	32
17	33.71	6.105	33.016	34
18	31.84	7.177	34.704	36
19	30.16	8.355	36.320	38
20	28.65	9.641	37.855	40
21	27.29	11.033	39.288	42

TABLE C.

ELEMENTS OF PARALLEL SPIRAL AT A DISTANCE OF 4.75 UNITS FROM THAT IN TABLE B.—Plate IV.

n.	Radius r.	x.	y.	l.
1	577.71	0.003	2.017	2.017
2	291.23	0.017	4.050	4.050
3	195.74	0.050	6.100	6.100
4	147.99	0.107	8.165	8.166
5	119.34	0.198	10.246	10 249
6	100 24	0.330	12.341	12.348
7	86.60	0.511	14.449	14.464
8	76.37	0.749	16.568	16.597
9	68.41	1.051	18.696	18.746
10	62.05	1.427	20.829	20.912
11	56.84	1.885	22.963	23.094
12	52.50	2.432	25.093	25.293
13	48.83	3.076	27.213	27.509
14	45.68	3.825	29.316	29.741
15	42.95	4.685	31.393	31.990
16	40.56	5.664	33.436	34.255
17	38.46	6.767	35.434	36.537
18	36.59	7.996	37.375	38.836
19	34.91	9.362	39.245	41.151
20	33.40	10.861	41.031	43.482
21	32.04	12.495	42.717	45.830

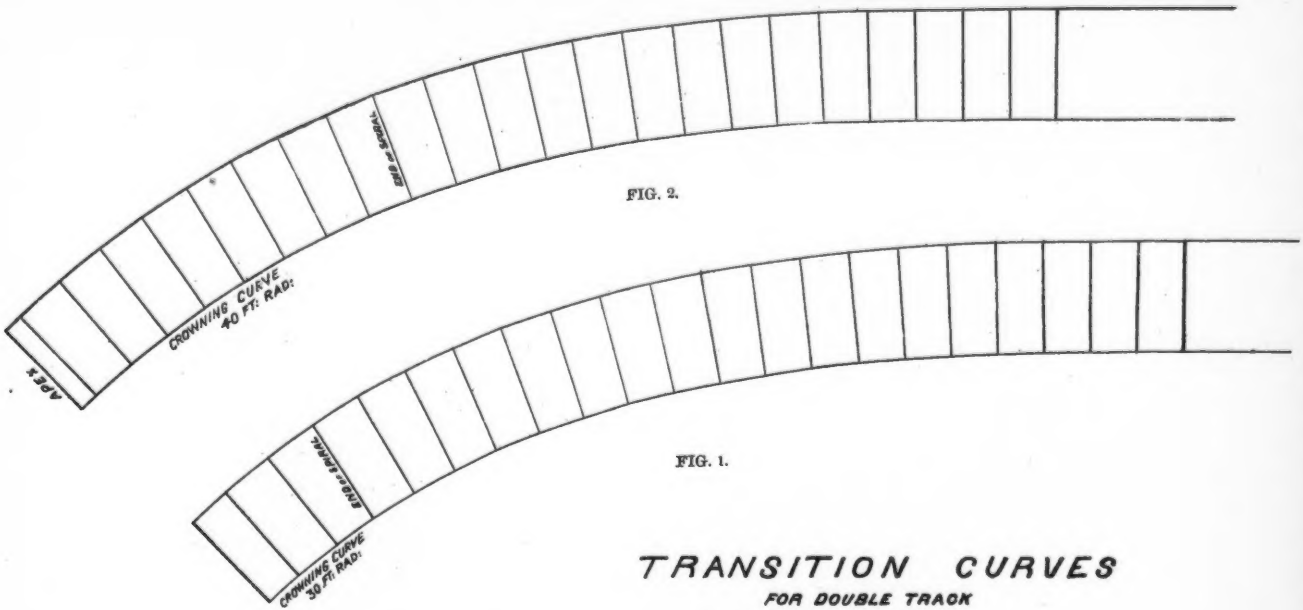


FIG. 2.

FIG. 1.

TRANSITION CURVES

FOR DOUBLE TRACK

30 and 40 FEET RADII

TOTAL CURVATURE 90 DEGREES

SCALE

Note.—For Ordinates see Tables B, C, D, E.

FIG. 3.

SEMI-TRANSITION TURNOUT

SPIRAL FROM 0 TO 8 AND CIRCULAR EVGE OF 70 & 74' 75 RADII.

Note.—For Ordinates see Table G.

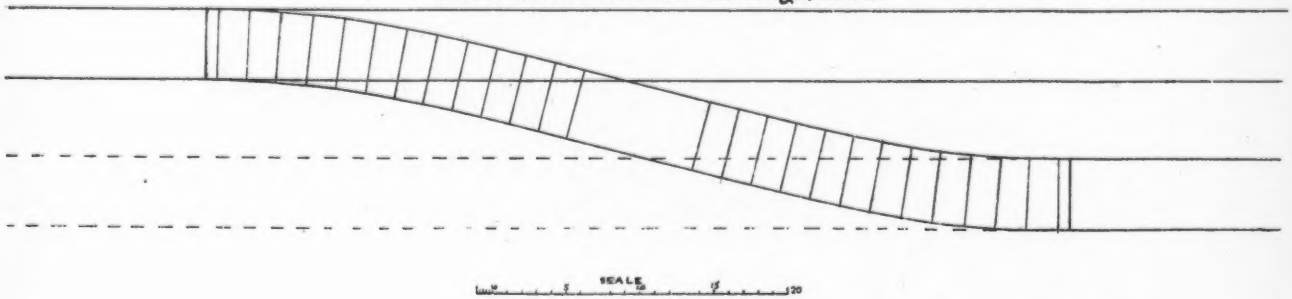


PLATE XIII
TRANS. AM. SOC. CIV. ENGRS.
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GRIBBLE ON
STREET RAILWAY TRACK.

FIG. 4.

FULL TRANSITION TURNOUT
SPIRAL O TO POINT 8.

Note.—For Ordinates see Table F.

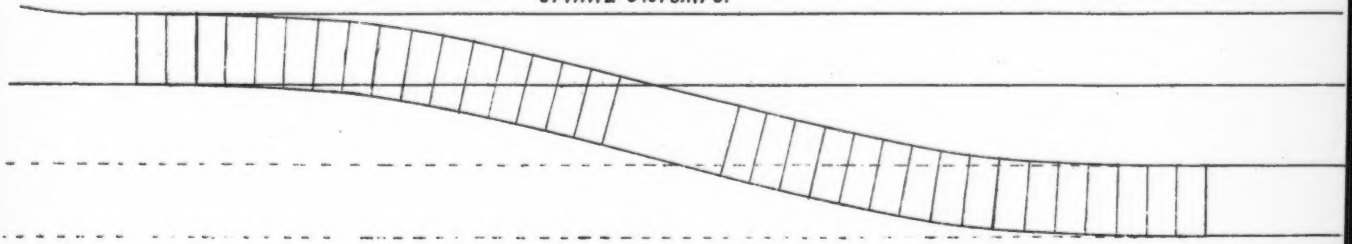


FIG. 3.

SEMI-TRANSITION TURNOUT

$IS = 21.88 +$ tan. 60.9 deg.: $\times$ [(16.40 cos. 45 deg.)—1.76]—16.40 sin. 45 deg. = 51.16 feet.

The intermediate way between the tracks is made 5.25 feet, but in order to make a harmonious transition from the inner spiral to a 30-foot crowning curve, the spiral has been continued to point 18, which makes the intermediate way wider at the crown. If it were necessary to keep the intermediate way the same width, it would be necessary to stop the spiral at point 12 where the radius of curvature is 47.75 feet, and there would therefore be a less perfect transition, but still practically imperceptible to the traveler.

Double track transition curves for a square street corner are shown on Figs. 1, 2, Plate IV, and the ordinates given on Tables D and E.

TABLE D.

Co-ordinates of Crowning Curves for Double Track Quadrants.—Spiral to End at Point 14.—Plate IV, Fig. 2.

Outside Track.

Co-ordinates of Outer Rail. Radius 44.75.			Co-ordinates of Inner Rail. Radius 40.		
No.	x.	y.	No.	x.	y.
14	3.825	29.316	14	3.509	27.613
15	4.675	31.387	15	4.269	29.465
16	5.628	33.413	16	5.120	31.277
17	6.679	35.391	17	6.059	33.045
18	7.826	37.314	18	7.084	34.765
19	9.067	39.177	19	8.192	36.431
20	10.398	40.977	20	9.381	38.040
21	11.815	42.709	21	10.647	39.589
22	13.317	44.368	22	11.988	41.073
Apex.	13.907	44.971	Apex.	12.516	41.612

TABLE E.

SPIRAL TO END AT POINT 18—See Fig 1, Plate IV.

Inside Track.

CO-ORDINATES OF OUTER RAIL. RADIUS 34.75.			CO-ORDINATES OF INNER RAIL. RADIUS 30.0.		
No.	x.	y.	No.	x.	y.
18	7.996	37.375	18	7.177	34.704
19	9.374	39.243	19	8.366	36.317
20	10.872	41.017	20	9.661	39.849
Apex.	12.193	42.413	Apex.	10.801	39.055

TURNOUTS.

The application of the spiral in Tables B and C to a turnout, will produce a switch nearly as easy as that of a steam railroad; but by reason of the accelerating curvature, a much less frog distance.

The diagram, Plate IV, Fig. 4, is composed entirely of spirals, but if the length of the turnout were longer than the authorities allowed, the diagram, Plate IV, Fig. 3, shows a semi-transition turnout which is composed of a circular curve for the switch, but forming a transition reverse-curve at the frog. The short piece of tangent at the frog relieves the car from the unpleasant swaying motion experienced when passing over an ordinary reverse curve. The ordinates are given on Tables F and G.

The author desires to state in conclusion that although he has endeavored to verify the accuracy of his calculations, it has been not without some apprehension that he has presented a novel form of construction to the criticism of an audience such as this.

He hopes, however, whether his views are shared by his hearers or not, that the historical *résumé*, and criticisms of modern types of construction, may furnish at least some suggestive thoughts to members of this Society.

TABLE F.

Co-ordinates of Full Transition Turnout.—Fig. 4, Plate IV.

Gauge, 4.75; Intermediate way, 5.45; Radii at crown, 71.62 and 76.37.

Left-hand Rail.

No.	*x*.	*y*.	No.	*x*.	*y*.
1	0.003	2.017	18 (P. S.)	6.205	40.829
2	0.017	4.050	19	6.699	42.767
3	0.050	6.100	20	7.183	44.708
4	0.107	8.165	21	7.649	46.653
5	0.198	10.246	22	8.093	48.603
6	0.330	12.341	23	8.505	50.560
7	0.511	14.449	24	8.879	52.524
8	0.749	16.568	25	9.210	54.497
9	1.045	18.679	26	9.489	56.477
10	1.395	20.767	27	9.712	58.464
11	1.788	22.829	28	9.882	60.457
12	2.217	24.868	29	10.008	62.453
13	2.676	26.881	30	10.095	64.451
14	3.153	28.875	31	10.151	66.450
15	3.645	30.848	32	10.183	68.450
16 (P. T.)	4.144	32.802	33	10.197	70.450
17 (Frog).	4.750	35.162	34	10.200	72.450

TABLE F.—(*Continued.*)

Right-hand Rail.

No.	*x*.	*y*.	No.	*x*.	*y*.
1	0.003	2.000	18 (P. S.)	6.056	39.648
2	0.017	4.000	19	6.555	41.602
3	0.049	6.000	20	7.047	43.575
4	0.105	7.999	21	7.524	45.569
5	0.192	9.997	22	7.983	47.582
6	0.318	11.993	23	8.412	49.621
7	0.488	13.986	24	8.805	51.683
8	0.711	15.973	25	9.155	53.771
9	0.990	17.953	26	9.451	55.882
10	1.321	19.926	27	9.689	58.001
11	1.695	21.890	28	9.870	60.109
12	2.107	23.847	29	10.002	62.204
13	2.551	25.797	30	10.093	64.285
14	3.017	27.742	31	10.150	66.350
15	3.501	29.683	32	10.183	68.400
16 (P. T.)	3.995	31.621	33	10.197	70.433
			34	10.200	72.450

TABLE G.

Co-ordinates of Semi-Transition Turnout.—Fig. 3, Plate IV.

Gauge, 4.75; Intermediate way, 5.25; Radii at commencement and ends Inner rail, 70.00; Outer, 74.75.

Left-hand Rail.

No.	x.	y.	No.	x.	y.
1	0.005	0.848	15 (P. S.)	6.165	34.097
2	0.060	2.986	16	6.659	36.035
3	0.175	5.118	17	7.143	37.976
4	0.351	7.248	18	7.609	39.921
5	0.590	9.368	19	8.053	41.871
6	0.883	11.462	20	8.466	43.828
7	1.234	13.552	21	8.838	45.792
8	1.624	15.614	22	9.170	47.767
9	2.054	17.652	23	9.448	49.746
10	2.513	19.667	24	9.671	51.732
11	2.990	21.660	25	9.836	53.726
12	3.482	23.633	26	9.944	55.723
13 (P. T.).	3.984	25.603	27	9.995	57.725
14 (Frog).	4.750	28.587	End.	10.000	58.518

TABLE G.—(*Continued.*)

Right-hand Rail.

No.	x.	y.	No.	x.	y.
1	0.005	0.794	16	6.518	34.886
2	0.056	2.796	17	7.010	36.859
3	0.164	4.793	18	7.487	38.852
4	0.329	6.787	19	7.946	40.867
5	0.562	8.773	20	8.376	42.905
6	0.830	10.752	21	8.766	44.967
7	1.162	12.727	22	9.117	47.057
8	1.534	14.691	23	9.410	49.151
9	1.947	16.648	24	9.649	51.271
10	2.391	18.598	25	9.825	53.401
11	2.857	20.543	26	9.940	55.533
12	3.341	22.484	27	9.995	57.671
13 (P. T.)	3.835	24.422	End.	10.000	58.519
15 (P. S.)	6.016	32.916			

DISCUSSION.

EDWARD P. NORTH, M. Am. Soc. C. E.—Before the technical part of this paper is taken up I want to call attention to a clause on the first page, where Mr. Gribble says: "But if her municipalities have erred on the side of leniency to corporations at their inception for the sake of progress, they have known also how to make up for it afterwards in rates and taxes." As this paper is read before this Society, and will have some weight outside of this country for that reason, I think Mr. Gribble should modify that statement. It has been utterly impossible so far, or until within a very recent time, to collect even the license fees for cars on our street railroads. I think that they are perfectly irresponsible to the city. They have in one instance altered the grade of the street so that it was necessary to remodel the street, and in a good many other cases they have gone on in this city entirely without regard to the ordinances of the Department of Public Works. I do not think they have ever paid any taxes, but I will not be certain of that. I think Mr. Gribble will alter that sentence if he investigates the matter.

E. E. RUSSELL TRATMAN, Jun. Am. Soc. C. E.—Mr. Gribble having referred to my paper, which was published in the Transactions, March, 1890, I am pleased to offer the following remarks in discussion of his paper. Mr. Gribble speaks to the point when he says that municipal authorities should stipulate that the materials and work in the construction of street railways should be under the supervision of an inspector to be appointed by them. I would go further, however, and say that the authorities should in the first place require the type of track and general form of construction proposed, to be approved by an engineer, and then that the materials and work should be under the supervision of an engineer and a competent inspector. Politics should not be allowed to enter into consideration in such work. The necessity of a good foundation for the track is universally admitted: the concrete base, 9 inches thick, of one English line is composed of one part of Portland cement, two of sand, and five of broken stone or gravel. As an example of the class of street-railway track very generally adopted in the smaller cities and towns (and not unfrequently found in the larger cities) of this country, I may instance a line in an Ohio town, the specifications for which were sent me in 1889. The rails were flat, of side-bearing section, 3¾ inches wide, and weighing 27 pounds per yard; they were spiked to stringers 15 feet long, 6 inches wide, 4 inches deep, which were placed upon cross-ties 5 feet 6 inches long, 6 inches wide, and 6 inches deep. The ties were spaced 5 feet apart in the clear, and the stringers were secured to them by cup-headed spikes 8 inches long and ⅝ inch square. At the rail joints there were bearing-plates 3¼ inches wide, 12 inches long, ⅛ inch thick. There was one curve of 40 feet radius upon which channel rails were to be used.

Much information in regard to track will be found in the reports of 1884 and 1885 of the American Street Railway Association; and I may

Fig. 20.

Improved Meakin Compound Rail.

mention (as Mr. Gribble recommends a gauge of 3 feet) that the report for 1884 advocated a gauge of from 4 feet 8 inches to 5 feet 2 inches. I quite agree with the author as to the desirability of having a removable wearing surface, and in this connection present a sketch (Fig. 20) of an improved form of the Meakin rail illustrated by Mr. Gribble. The rail proper is in two pieces, which are dropped into place in the head of the iron longitudinal, and are secured by a slightly taper bar which forms the bottom of the groove; this form of rail is said to have been tried in

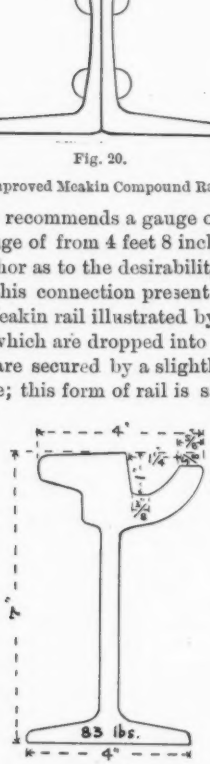


Fig. 21.

Grooved Girder Rail; New York, N. Y.

England on the Southeastern Railway and on the South London Tramways. A very good track for country roads can be made with ordinary tee-rails, and for particulars of such track I would refer to an article of mine on "Country Tramways," published in *Engineering News*, New York,

April 6th, 1886. With a good type and construction of track, there should be a good street foundation, and paving from curb to curb, as in England and other European countries, where grooved rails are used. In regard to several remarks which have been made as to the street paving, I would say that it would be poor policy to adopt a good system of track for a city street, without adopting a good pavement. Without such pavement, ruts and an irregular surface will be formed, and the advantages of the improved track be thus lost to a considerable extent. As already stated in my paper (*Transactions*, March, 1890), I believe the grooved rail to be the best form for city streets, while the trouble from clogging of the groove is probably exaggerated. In some English cities I have seen a water-cart used, which has the wheels set to the gauge of the track, and which has two small pipes leading down close to the ground and delivering a stream of water into the groove of each rail. In other places there are track-walkers with long-handled scoop shovels; a tongue projecting from the front edge of the scoop, fits into the groove of the rail, and as the man pushes the scoop along the rail the tongue slices up and throws out the dirt in the groove. The companies might object to any such extra expense, however small, but the general construction and surface of the street for the use of the public, should be given prior consideration to the desires of the companies. The grooved rail to be used on the Broadway and Third avenue lines in New York, when the cable system is introduced on these lines, is shown in Fig. 21; it weighs 83 pounds per yard; the West End Street Railway Company, of Boston, Mass., is using a girder rail with side-bearing head (Fig. 22). As to the

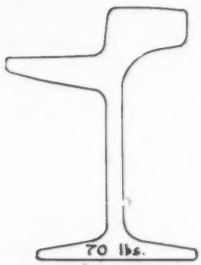


Fig. 22.

Side-Bearing Girder Rail; Boston, Mass.

English girder rail, Mr. Gribble says: "It rests upon a longitudinal bed of concrete, which covers its flanges and maintains it absolutely immovable." In many cases, however, the rails are secured to wrought-iron or steel longitudinals or cross-ties embedded in the concrete, as shown in Fig. 23. That of course is a more expensive method of construction than where the rails are laid only upon the concrete. A

form of rail which is used to a limited extent, is a rolled "box-girder" rail, on somewhat the same principle as the Deas cast-iron box-rail illustrated by Mr. Gribble, but having flanges at the bottom. The rolled rail is 3 inches wide (tread, 1½ inches; groove, 1 inch; guard, ¼ inch), 4⅛ inches deep, and 6¾ inches wide over the bottom flanges. Its weight

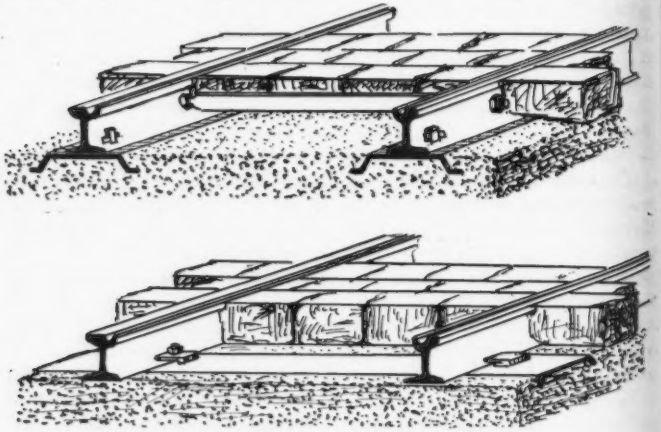


Fig. 23.

European Girder Rails on Metal Longitudinals and Cross-Ties.

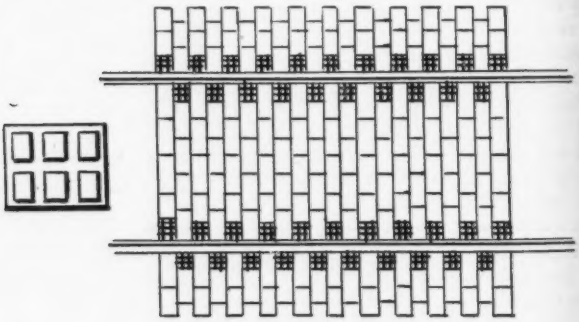


Fig. 24.

Iron Paving Blocks. Scotland.

is from 65 to 75 pounds per yard. At the joints the rail ends rest on a cast-iron plate or chair, about 9 inches square, the outer flanges being held by a lug on the chair, and the inner flange by a bolted clamp. The two chairs are connected by a wrought-iron tie-bar, the ends of which are

turned up to pass through holes in the chairs, and are secured by keys lying in the hollow of the rail. For city streets timber should not be used at all. In regard to the rigidity of the track, which is advocated by the author, some of the English lines are very unpleasant to ride upon, there being a constant vibration and noise in the car. This may perhaps be due, to a certain extent, to the construction of the cars and their springs, but I think a considerable portion is due to a great rigidity of the track. Spiral or transition curves have been tried with success on the Denver and Berkeley Park Rapid Transit Co.'s dummy line, at Denver, Col. Particulars were given in a paper read by Mr. E. L. Woolley, at the Convention of the American Street Railway Association, in October, 1890. (See *Engineering News*, New York, Nov. 1, 1890.)

The ordinary vehicular traffic coming upon street railways has always been a source of trouble, by causing ruts or grooves in the paving along the side of the rail-bed. While in Europe in 1890, I noticed that on some lines at Edinburgh and Aberdeen, there were iron paving-blocks next to the rail, placed alternately with the granite blocks, as shown in Fig. 24; the blocks were about 4 inches by 6 inches, chequered on top. A plan proposed for the same purpose for the Southampton tramways, was to insert thin steel plates in the transverse joints of the granite paving-blocks next to the rails.

In regard to the form of track designed and patented by Mr. Gribble, one feature, which appears to be an objection, is the extreme shallowness of the rail. It is merely a strap rail, without any stiffness in itself, depending entirely upon the key fastenings, to hold it stiff and rigid on the iron and concrete longitudinal. The lug and key system of fastening for rails, promises well; but in this case, the shallowness of the rail necessitates the use of a very large number of keys, to give a practically continuous fastening of the rail. It is a question whether a simpler form of track might not be obtained, by using more metal to stiffen the rail, and less metal in fastenings. For lines with heavy traffic, I should be disposed to prefer a track with saddle or flangeless tee-rails, carried on iron chairs, as illustrated in my paper in the Transactions, March, 1890. The real merits of the flat-rail track can, however, only be arrived at after a sufficiently long test in service, to allow of comparisons being made. It is to be hoped that such a service trial will be carried out, as the general form of the track proposed by Mr. Gribble appears to present some advantageous features.

GEORGE R. HARDY, M. Am. Soc. C. E.—I understand that system C is designed for heavy traffic; is there provision enough in the design for extensive wear? It seems to me that after a certain amount of wear, the half of that rail would be worn so thin as to render it dangerous. The question has been raised: If the top wears, why not the bearing also? It requires a large amount of material in the head of a rail to provide

for wear, and to that extent the rail will be much less efficient in proportion than the Sandberg rail would, after a given amount of wear.

Mr. GRIBBLE.—I apprehend that it will wear just as long as the hardness given it enables it to; it will be perfectly safe to give it a great hardness, and the amount of wear upon it can be gauged similarly to any other rail. If an ordinary rail wears too long it is in danger of total fracture, but this rail is supported when worn through because the rolled beams remain intact. The removal of this rail is so simple a matter that it can be taken out and examined, if necessary, after a certain number of years' wear.

Mr. A. J. HUTCHINSON.—I am a practical street-railway man, and I would like to ask Mr. Gribble if he considers that the joint of his rail is properly cared for. I find that the great wear is at the joints, that the decay comes first at the joints; that the rails are sometimes rounded at the ends before the center of the rail is sufficiently worn to throw them out. My experience extends back to about 1854, in connection with the Fourth avenue road. I was there when Mr. Allen Campbell was president of the road, and when the Vanderbilts came in. Probably some of you remember a piece of track laid in Broadway in 1862, between Thirteenth and Fourteenth streets, which I laid. In about 1861 I laid a section of the first girder construction (that is, what you would consider a girder construction) that was ever laid in New York, a single section laid in front of the car depot, corner Centre and Elm streets, where one of your members says the street surface has been so changed by the railroad companies as to make it necessary to change the grade of the street. Mr. Campbell said to me one day that they were likely to lay a track down Broadway, when they would require something to lay on the concrete, and suggested that I get up some form of rail for that purpose, which I did; it had a horizontal base or flange about 12 inches wide, and a perpendicular web of about 8 inches, upon top of which was a form of rail something like the flat-grooved rail of to-day. That was in use about two years, but there came a time when it was necessary to put a side track between the depot and the Tombs building, and it was taken up to make room for the switches.

My experience has been that the wear comes at the joints more than at any other portion of the rail. I am in favor of the railroad T rail; that rail, laid with chairs or with special supports, properly paved on either side, makes a very durable track, and not too rigid. I believe there is such a thing as having too rigid a rail. If it is too rigid there is a pound at the joint. My objection to some patterns of rail is that at the joint the rail and chair are clasped together, which makes a rigid joint at the chair and the tie. The fish-plate joint is not connected with, but separate from, the chair, and is the best joint that I find. I like the idea of using concrete if you will only get rid of the motion of the joint, which

must necessarily come with wear. I like that construction, but with the exception that there is, of course, some give at a flat rail joint, and there is a constant pound under such circumstances.

Mr. JOHN D. ELWELL.—Every effort to improve street railway tracks is confronted at the outset with a difficulty occasioned by expansion and contraction. The constant movement, backward and forward, of the rail cannot be repressed. It must be recognized and provided for by such devices as shall effectually serve to neutralize its mischief-working powers. It is therefore of prime importance in any well advised consideration of street railroad tracks, to first regard them at points at which movement is taking place, and to require, *sine qua non*, that there the structure under the prevailing condition of ceaseless movement, shall be equal to the burden it has to bear. And inasmuch as "strength at the weakest part," is the measure of strength, a street railway should be as strong and in all respects as perfect at its joints, as at any other point.

The value of a joint is, that there expansion and contraction can be provided for. There are no mechanical or other difficulties in the way of lapping the metal of the rails, so that expansion and contraction can take place without the slightest weakness of any kind at the points where allowance for this movement is made. It must however be said, that this can only be accomplished, so far as is at present known, by causing the rail to be its own fish; and with a series of under and over lapping of its parts do away with the necessity of otherwise making a complete break at any point within the length of the track.

This simple alternative is presented: Either the rail is rolled in two webs, and by breaking joints, creates a track that is at each "semi" joint as strong as elsewhere; or the rail is rolled in one web with a complete break at each 30 feet of track, and a weak spot at each joint, in spite of any extraneous connection that has yet been devised, or that apparently can be devised, taking expansion and contraction into account.

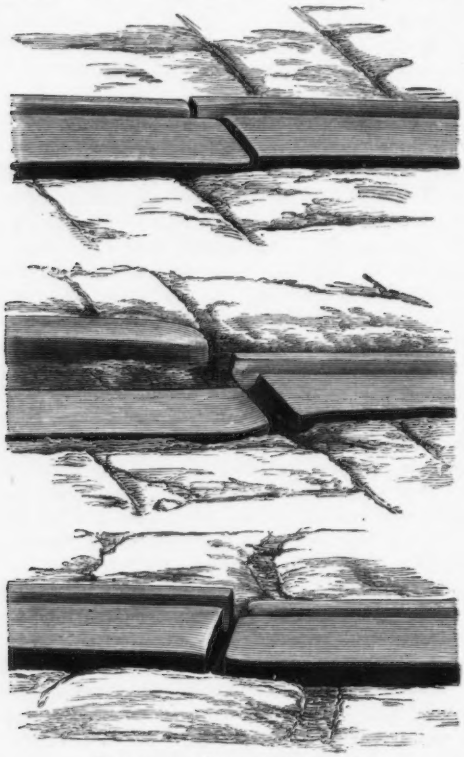
Previous to discussion of road-beds, fastenings, or shape of rail-heads, this fundamental consideration must be determined: Shall the track be a homogeneous whole, woven together so as to obtain unity in all its length, with such provisions for expansion and contraction as to entail weakness nowhere; or, shall the track be composed of unrelated rails, save by an unnatural and insufficient connection, powerless to prevent weakness, at each thirty feet.

Two unqualified assertions are here recorded:

(*a*) No mechanical difficulty exists to interfere with the production of a track, which for all practical purposes is equally strong at every point in its length.

(*b*) No mechanical contrivance exists that can prevent great weakness at each joint of a track made up of unrelated rails, save as they are hitched to each other by longitudinal fastenings.

Adherents of the systems requiring a complete break, so far as the rails are concerned at each 30 feet of their tracks, are naturally puzzled with the question of how best to dispose of their joints, when they have created them. If suspended, they straightway wabb'e with every passing train. If bedded on a metal chair, the chair immediately becomes an anvil for the speedy lamination and destruction of the rail ends. Giving to its metal chair, a curious resemblance to a miniature anvil,



Specimens of Depressed Rail Joints.

was surely a stroke of unconscious humor on the part of the inventor or inventors of the system of clip-fastened track variously claimed in Boston and Brooklyn.

There is a factor in the problem of street railway tracks that does not obtain in steam railway tracks. On steam railways, all the fastenings of the rails and the structure are open to constant inspection, and

the vigilant trackman is perhaps able to "take the stitch in time that saves nine," but on street railways, with everything covered, no such daily correction of "the beginnings of evil" is possible, and every slight irregularity is speedily magnified.

Recognition of this special factor in street railway construction, has led an ingenious official of a well-known Boston Street Railway Company to devise a box with an iron cover, enclosing each joint of his track, which can be opened and the joint connections regularly wound up as one does his watch. His invention is at least a recognition that no non-exposed longitudinal fastenings which have yet been devised, are capable of long withstanding the shocks of electrical traction. Innumerable illustrations of this can be produced. Under the shocks of electric traction, the most recent and carefully constructed street railway tracks exhibit painful evidence of weakness in their low and defective joints, alike destructive to rolling stock and the comfort of travel. The accompanying cuts of the Fourth Avenue Railroad Company's track in Vanderbilt avenue, New York, laid in 1889, are illustrations of the hundreds that might be produced, in demonstration of the incapacity of longitudinal fastenings to properly connect street railway tracks. Such illustrations are daily within the personal observation of any one willing to notice them, and they will be perpetuated and multiplied so long as a radically vicious method of rail connections is adhered to. It may be definitely stated as beyond question, that no multiplication of devices or expedients to postpone the ill effects of this faulty principle of construction can produce results proportioned to expense.

An English fad—fortunately as difficult to introduce into general use in America as the single eye-glass—is a street rail weighing 100 pounds per yard, of which 7 per cent. represents its head-wearing capacity, and 93 per cent. its scrap residue. Discarding all chairs, its broad foot is intended to rest directly on a solid bed of concrete. At the end of six or seven years the rail has reached the limit of head-wear, and the track must be entirely torn up, travel completely interrupted, and a new rail supplied. The scheme has much to recommend it to rolling mills with a surplus product of steel. But apart from the discomfort of riding on so absolutely inelastic a track and its speedy destruction to rolling stock, the short service rendered by the rail for so great an expenditure of material, and the serious annoyance of a complete interruption of travel at its frequent renewals—the track lacks at its best estate homogeneity; and at every 30 feet of its length, vibratory waves set in motion by travel, break with a shock that speedily renders abortive this special effort to perpetuate the device of hitching together rails to form street tracks.

There have been various attempts to unify rails of steam railway track, by dividing their webs into two parts for the purpose of lapping joints. Heretofore such efforts have been on lines incapable of com-

manding success; and all of them for at least one potent reason, namely, that having divided the rails into two webs, they proceed at once to reunite them with bolts and nuts, which inevitably shake loose with the movement of expansion and contraction, and the working and pressure of travel.

In June last, patents were issued for the invention of the bearing of the one web of a divided rail upon the other web with full liberty of expansion and contraction, uncoupled by bolts and nuts. This fundamental principle, therefore, of the duplex lap-joint rail, differentiates the Gibbon system of street railway tracks from any other. It apparently solves the problem of the construction of a street railway track having equal strength, smoothness, and elasticity at every point in its length. Of absolute simplicity of construction, it reduces to a minimum the number of separate metal parts employed to constitute the complete track. As a matter of fact, it employs considerably less than one-half of the number of separate metal parts required by the other system, assembling its maximum number (seven) at the semi-joints, viz.: The 3 parts of the rail—1 chair, 1 tie-bar, 2 lock wedges; total, 7, as compared with the upwards of forty separate pieces of metal assembled at each joint, by one of the most used splice-bar systems of tracks.

The following claims are made for this system:

(*a*) The material can be furnished at a less cost than for any other girder construction, and can be laid at less cost than the track of any other system.

(*b*) The maintenance and repairs are reduced to a minimum.

If the effort to improve street railway tracks is confronted at the outset with the difficulty of obtaining a track equally strong, smooth and elastic at every point in its length, it is next met (such track having been secured) with the problem of laying it to the greatest advantage.

(*a*) It should be laid on a sufficiently permanent foundation to at least avoid any necessity of a renewal of the substructure when the track is renewed.

(*b*) It should be laid so as not to be absolutely rigid, but sufficiently elastic for the ease of travel and the conservation of rolling stock.

(*c*) It should be laid so as to allow of rapidity and economy in repairs, with a minimum disturbance of the street surface.

The use of wood as the substructure of street railway tracks should be prohibited by municipal ordinance, wherever in city streets track has to be relaid. An enlightened self interest should be a sufficient restraint, but at times those intrusted with the management of street railroads are financially interested in pushing "a timber railroad with a capping of iron."

An indestructible substructure, that does not interfere with proper elasticity, and preserves all the strength required to resist vertical and lateral thrusts of traffic, may be obtained by intermittently supporting the

track at not more than 5 feet intervals, on properly constructed metal chairs resting on concrete foundations.

The whole modern bent is toward speed, and it may be set down as definitely settled, that the requirements of elasticity in a railway track are in proportion to the speed acquired.

Nothing is more thoroughly proved, by actual experience, than the unequal wear of the rail surfaces in crowded thoroughfares subject to heavy vehicular traffic. At one point in the line of track, the head of a rail will be seriously abraded. At another point the tram of a rail will be injured. At certain points on the line of track the natural wear of the cars' wheels on the head rail, will be almost the only attrition. At another point, the scraping of the tram by drays will greatly exceed the head wear. Rapidity and economy in repair with a minimum disturbance of the street surface, can be obtained under a system that discards no more of the rail than that part which is injured or worn out.

The following are fundamentals as regards street railway track:

First.—It should possess in the fullest measure the strength, smoothness and elasticity needed at every point in its length.

Second.—It should be laid on an imperishable substructure, so as to fully preserve needed elasticity, for the comfort of travel and the conservation of rolling stock.

Third.—Its design should allow of repairs and renewals with ease and rapidity, and a minimum disturbance of the streets.

A decent regard should also be had for economy at least to the abandonment of all attempts:

(*a*) To wheedle a wrong principle of construction into a proper service by a complication and multiplication of parts.

(*b*) To bully a wrong principle of construction into a proper service by sheer bull-headed superabundance of material.

Minor considerations, such as the shape of the head of the rail, depend largely on special conditions. A good system of track should meet all such requirements and adapt itself equally to side bearing, center bearing and grooved rails.

So also, as to weight of rails; the country road with horse traction does not require as heavy a section, as the crowded thoroughfare with electrical traction; but rails from 38 pounds per yard to 78 pounds per yard may be accepted as the very extreme of desirable weight.

So long as the overhead system of electrical traction obtains, a track that will serve as the medium for the return ground current of electricity without a reinforcement of copper wire at its joints, is much to be desired.

In this respect the duplex lap-joint track possesses the advantage of absolute contact of metal in its entire length, and under such conditions as prevent electrolysis. Its box shape furnishes a perfect vertical wall

for the support of the pavement, and with a permanent substructure, it avoids the absolute rigidity of a track continuously supported by a non-elastic foundation.

If 7 000 pounds is regarded as the maximum weight that in practice is placed upon any one point of a street rail, the duplex rail of weight mentioned by Mr. T. C. Gribble is from twice to four times (according to the spans) stronger than is necessary as regards its working load; sustaining such load at least one-fifth below the allowance of $\frac{1}{10}$ of an inch deflection for each foot span. At from 5 to 2 feet spans it is eight times to twenty times stronger than is required to sustain the maximum weight that in practice would be placed on it, as regards its breaking load. No such weight, therefore, viz., 78 pounds per yard, as suggested by Mr. Gribble, is required in any street. Not even for the heavy vehicular traffic of Broadway, New York.

The duplex lap-joint track is the only system that avoids fatal weakness at the joints, and it therefore alone responds to the fundamental requisite of a good street railway track.

THOMAS H. GIBBON.—The agitation which has long existed in the public mind, and also in railway circles, respecting the form of rail that ought to be used and the general construction of street railways, is evidence that the present systems are defective, costly in maintenance and a source of annoyance to the public. Street railways, as a rule, have done and are doing much for the convenience and comfort of the people. They have increased the value of property upon the streets in which they run; but this is offset by the continual tearing up of the streets for repairs and renewals, thus obstructing the public thoroughfare. This is not the fault of the railway companies, but of the systems which have been given them for adoption. The people naturally expected, when they gave these valuable privileges to the railway companies, they would receive in return a track which would give smooth and rapid transit, and at moderate charges, and so designed that the public vehicles could use it. Therefore more than ordinary care should be exercised in the analysis of the various systems now in use, to point out their defects, and devise such betterments as will meet the approval both of the railway companies, and the people. But before we analyze the existing systems, would it not be well to find out what are the requirements that will constitute and make a perfect railway track.

The essentials deemed necessary for this improvement are—

First.—All material used in track construction should be of imperishable character.

Second.—Its design should be simple and its parts few and easy of access, so that the part worn may be renewed with rapidity, and with little disturbance to the street pavement.

Third.—It should not possess more material than is absolutely

required to carry the load for which it was designed, thus effecting an economy in first cost.

Fourth.—It should possess elasticity (not rigidity); this would insure the comfort of the passengers when traveling, and preservation of the rolling stock.

Fifth.—It should possess lateral as well as vertical strength, and be able under any circumstance to keep true alignment, grade and gauge. This would lessen repairs.

Sixth.—It should be free from depressions at the joint, in order that the load which it has to carry may be transmitted uniformly and rapidly, with the least possible oscillation.

Seventh.—It should be of the stringer form, thus giving stability and a firm support for the paving.

Eighth.—The rails should be either side-bearing or grooved, both rails having a broad face surface, so that the public trucks could pass along them smoothly and rapidly. The former would be the best for the railway companies, the latter entailing some expense to keep the groove free from dirt and ice. Either would meet the public requirement, providing they have broad running surfaces.

The various types of rail and foundation material that have been applied to meet the real requirements in connection with street railway construction in Europe, are well described in Mr. Gribble's paper. The paper has much food for reflection, digestion and rejection, but Mr. Gribble has failed to touch upon some very important points in track construction and maintenance, which must be accomplished within the bounds of financial prudence in first cost, coupled with simplicity and economy in repairs and renewals, before either the railway company or the people will be satisfied. He has not dealt sufficiently with the joint connection—the weakest and therefore the most important point in track construction.

Should there be elasticity in a railway track ?

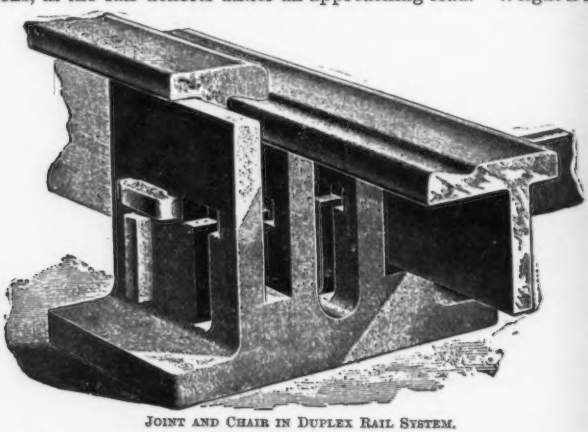
It is a matter of history that railroad tracks were at the first made as rigid as possible, but experience soon demonstrated that such tracks were unpleasant to ride upon and caused rapid deterioration to the rolling stock. Step by step the idea of solidity gave way to that of elasticity, the stone foundations used were discarded, and wood ties with gravel ballast substituted. Even this lacks elasticity under certain conditions, and in winter, under the action of frost, it becomes rigid and even dangerous through unequal bearings, and the consequent breakage of rails.

Metal ties have been found to give all the strength required for steam railway service, and the ballast filling acts as a cushion for easement of travel and preservation of rolling stock. During the past twenty-five years over 12 000 miles of railway track in Germany, Netherlands, Belgium, Austria, Hungary, India and other countries, have been laid with

metallic cross-ties or metallic longitudinal stringers. The first street railway using metal ties in the United States was built in Albany, 1884. In 1889 a report was given by its president, *vide Street Railway Journal*, September, 1889, stating that "It is an easy-riding track, and being smooth there is less noise than on ordinary timber tie and stringer track."

Why a Longitudinal Box Form System should be Used.

Cross-ties bedded in ballast sink irregularly under the action of traffic, partly by compression of the ballast beneath them (to an extent tending toward a limit as consolidation of the bottom ballast progresses), and partly by its being forced out laterally. This detrusion of material from beneath the cross-ties, is effected by pressure combined with vibration and oscillation, acting directly upon those portions of a mass of inelastic and non-coherent material that are in contact with the cross-ties. Mere downward pressure displaces ballast sideways; vibration increases the effect, and oscillation of the cross-ties, by which pressure and vibration are made to act successively in different directions, is yet more effective to produce movement of the particles away from the point at which they are subjected to disturbing actions, as the rail deflects under an approaching load. Weight is first



Joint and Chair in Duplex Rail System.

thrown upon the near edge of the tie, causing it to compress and sink; rising again, the cross-tie has rocked under the load until the far edge has become lower. This rocking motion of the ties displaces the material from the field of downward pressure, hence the low joints and irregular track.

In order to maintain the accurate adjustment to level demanded by the traffic, constant shimming and raising of the track is required, which entails large expense, and becomes impracticable in paved streets.

With longitudinal supports the case is different, the oscillation travels with a wave of deflection, and the effect is to distribute the material lengthwise of the road until equilibrium is automatically attained; therefore there is no possibility of irregular depressions in the track except at the joints, and not even there, if the rails are woven together by lap jointing. It may be said, therefore, that the maintenance of a longitudinal system to accurate level, and consequently to proper line, will be less costly than is the case in the cross-tie system.

Duplex Rail Joints.

The engineering mind in all parts of the world, for years past, has been directed to the solution of the problem of how to connect the rails of a track as to make them practically continuous, and when the fish-plate was introduced, success seemed to have been attained in a high degree; but since the birth of the fish plate the speed of trains has increased, and, with that, such an irritation has come upon even the best fish-plate devices that their life and utility are but of short duration. Let us look for a moment at one of the best fish-plates. We find it can only be connected to the rails by means of four holes (which are destructive to strength of rails), four bolts, four nuts and four washers, making fourteen separate pieces to make this connection. Let us even suppose that drilling holes through the web of the rail, and slotting the flange for the spike, did not weaken the rail. The pressure upon the steel surrounding the bolt holes is so immense, that the best steel can only resist for a short time, friction is caused by every passing train, and the nature of the rail is changed. Each of the fourteen parts composing the fish-plate joint, which were banded together to act as one, becomes loose, and that unity which is required for strength is severed, hence their combined strength is gone, and low joints (always the fruit of weakness), fractured rails and wreck, is the result.

It is well known to managers and practical engineers that the joint is the cause of fully 50 per cent. of the expense of track maintenance, and therefore rolling stock repairs. The trackman's principal labor is in raising low joints. The army of mechanics in the company's shops are largely employed on repairs of engines and cars caused by low joints. The spring and wheels of rolling stock are not broken by gliding on the rail between joints, but by the sudden jarring in crossing over the joints. Now why are there any low joints, when so much material is used? The joint has two plates, weighing from 35 to 50 pounds, besides the nuts and washers needed to secure the two rails together. It would appear at first sight, with all this additional metal, the joint should be the strongest part of the rail, and so it would be if these plates, bolts and nuts were in one solid mass, but they are not, and cannot be put together so firmly—allowing for expansion and contraction—as to make them one; hence the joint is the weakest part of the rail and is

the first part to yield. The chair joint, the narrow fish-plate, the fish and angle plate, the fish-plate and chair combination, all have been tried and found wanting. For proof of this look at our best laid tracks, the joints can be counted by the depressions existing in them, and these depressions cause hammer blows from every passing wheel, and destruction to the rail. In one mile of track we have upwards of 350 joints, which must be closely watched and kept up by some means. Trackmen patrol their sections night and day, screwing up loose bolts and packing up low joints, and yet fail, as the enormous expenses of the repair shops demonstrate. Such is the experience of steam railways. In street railways it is worse, for the ties and fish-plates are below the pavement and cannot be got at without tearing it up. This is very expensive and an obstruction to the public travel, hence the imperfect track which now exists. Fifty years of experience demonstrates that the present system of jointing the rails is very expensive, destructive, and very imperfect.

The Form of Rail.

As street railways are made for the people, it is absolutely necessary that they should be satisfied. Does the T-rail satisfy them? The press says no very emphatically. It must go. It has been found dangerous to public traffic, and destroys the pavement. A side-bearing rail with broad tram would be more convenient for public traffic, and its use would reduce the formation of ruts which now exist in the pavement where the T-rail is used.

The systems used in Europe and illustrated in Mr. Gribble's paper show them to lack in virtues which are needed for an economic and serviceable street railway.

First.—They possess excess of material.
Second.—They are too rigid in character.
Third.—The joints are defective.
Fourth.—They are too expensive in first cost.
Fifth.—They incur a maximum cost in renewals instead of minimum cost.

The concrete foundation and heavy grooved rail have been introduced in Washington and Pittsburgh, the track at the latter place costing upwards of $30 000 per mile. The rail has a wearing capacity of only about 8 pounds per yard, which eight years will perhaps wear out, and then will come the renewals. These involve blasting of the concrete to get out the rails, tearing up the streets, and a great interruption to the traffic, all involving expense and a trial of patience.

And now a few words on the American systems, the Johnson, the Wharton, the White, or the Lewis & Fowler systems.

The two former are of the single-girder type, using rails sometimes with and sometimes without bottom flange, fish-plates, chairs, spikes, bolts and timber cross-ties; they are defective, inasmuch as they cannot resist torsional strains, they lose gauge and are weak and defective

at the joint, a difficulty inherent to all splice-bar systems. They are reasonable in first cost, but equally expensive in renewals, entailing a general tearing up of pavement and discardment of all the material, as in the English systems.

The White or Lewis & Fowler system, being of box form, possesses more stability, consequently better gauge and alignment will be kept, but the joint difficulty exists, as in the systems alluded to. It supports the paving better than the Johnson, but does not give a perfect support, as the splice-bars and bolts protrude from the face of the girders at a point too near to the surface of the street; consequently the paving blocks having greater depth cannot come close to the girders of the rails, without the blocks being chipped to fit the bolts and splice-bars. It is more expensive in first cost of material, and uses timber cross-ties, chairs, spikes and splice-bars; and is consequently more expensive in renewals, discarding the whole of the material except about 8 pounds of head wear, and entailing a general tearing up of the pavement to do it. From the rail being in one piece and of box form, it is more difficult to roll, and it is impracticable in anything but a straight track.

The Gribble system (judging from the drawings) is more complex than any of the other English systems. It does not eradicate any of the objections which they possess. It is too massive and rigid; it possesses more material and greater strength than is necessary for street car service. The castings and rails will have to be of the finest fit, so that they knuckle to each other snugly, and even then with no assurance of smooth joints. On the contrary, the rails at their connections will have a tendency to work loose and upwards, on account of the castings not having any absolute anchorage in the cement, which is liable to crack or indent from the hammer blows and vibrations, even of the cars. Again, the lugs on the cast iron girders, which hold the rails in position, being near the surface of the street, are liable to be broken by trucks, and should the pavement be rutted or sunken along the track, these lugs would surely break or become unserviceable (no matter what they are made of), and the rail would become loose. True, not so much metal is thrown into the scrap heap at renewal, but that is almost counterbalanced by the destruction of the cement. The gas pipe tie-bars, have to be screwed up to gauge and kept there, but how I won't say. It may be as expensive in first cost as the English systems, and almost the same in renewals. Some portion of the fixings are imbedded in the cement, and consequently on renewal must be destroyed. This system may have 8 pounds of head wear. The laying and repair involve the employment of a large amount of skilled labor.

The metallic track, laid in November and December, 1884, at Albany, N. Y., was the first all metal system laid in the United States, and does not require spikes, splice-bars, bolts, nuts or rivets. This system is alluded to in Mr. Tratman's paper, already referred to, as "using cast-

iron stringers, filled with sand. * * * * This track has been in service for about four years and has given good service."

It is composed of hollow cast-iron boxes about 6 feet long—open at the top and bottom, having mortises on the ends, to receive the pendant of the rail, and T-shaped mortises on the sides, the vertical part to receive the notched transverse tie-rods (which hold the track to gauge), and the horizontal part to receive the wedge key, which, when driven through the mortises in the castings and pendant of the rail, passes over the tie-rod, and locks all the parts together. The rail was of side bearing section, weighing 40 pounds per yard. In 1889 more track was laid of this system, but instead of filling with sand, the boxes were filled with cement, upon a cement foundation. The verdict was: Too rigid.

In laying this track, longitudinal trenches, about 15 inches wide, were dug for the stringers and transverse treaches for the tie-rods by taking up the paving, leaving the crust of the earth undisturbed. The castings were placed longitudinally in the trenches, 2 feet 3 inches apart, and after being coupled together by the transverse tie-rods, which gauged the track (the rods being notched to the gauge required), were then filled with sand, and tamped, then the rails were dropped into the guides or end mortises in the stringer, bringing the mortises in the pendant of the rails in line with mortises in the sides of the stringer, after which the keys were driven as before described. If care is used in placing the stringers, very little surfacing or lining is required. This system was also laid in December, 1884, in Fulton, N. Y., and on the Southern Boulevard Railroad, New York, in 1888.

The system just described has been demonstrated to possess great merits, but it has the defect of employing cast-iron stringers. The castings are liable to break, and would not be serviceable except in well paved streets; besides there is an excess of metal for the work to be done; the cast-iron stringers weighing 60 or more tons per mile.

A realization of these defects led to the introduction of the "duplex rail" and "lap joint system," illustrated in Mr. Gribble's paper. By it the metal is so distributed as to make a rail and continuous stringer of steel, without any increase of quantity, and its duplex character has solved the "joint" problem. It substitutes for the "fish-plate" or "splice-bar" joint, a lapping of the rail at the joint, the rail becoming its own fish or splice.

To accomplish this, the rail proper is rolled in two distinct parts, the "head" part and the "tram" part. The "head" part resembles the letter T, the tram part resembles angle iron. When these two parts are put together, the head part rests on the tram part, and combined, they form the rail, and three sides of a box, and on top is the side bearing, center bearing or grooved rail, as required. These two parts are arranged, so that there is no complete break in the track anywhere. Where the

head-rails connect, the tram part is a solid support at that point. Where the tram rails connect, the head part is solid above them; practically making a continuous rail. A track thus built, gives equal strength at every point of its length, thus giving uniform elasticity, for the transmission of the loads. It is an "all-metal" system, having metal chairs with large base plates, for the rails to sit in and rest upon. The transverse tie-bars are notched to the gauge required, and the girders of the rail fit into these notches, thus keeping the gauge absolute. The system discards all splice-bars or fish-plates, bolts and nuts, the parts being fastened by a wedge, known as the automatic spring key, which not only locks all the parts of the track together, but also locks itself in. Fig. 25 is a sectional plan of a joint showing the wedges in place.

The following advantages are claimed:

The durableness and permanence of an all-metal system.

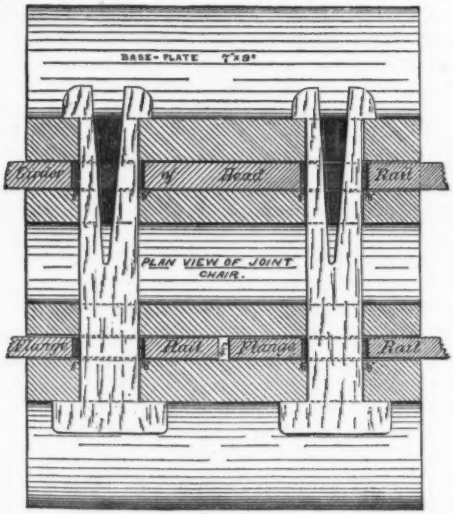


FIG. 25.

The smoothness and stability of a track absolutely free from weak joints.

Increased vertical and lateral strength with no increase of metal.

Freedom from torsional strain—the bearing surface being directly supported by the vertical webs.

Increased wearing capacity of head-rail.

In renewal, the discarding of the worn portion only and not the entire rail.

Perfect alignment and accurate gauge maintained, with required freedom for expansion and contraction.

Simplicity of construction, giving rapidity in track laying and a minimum disturbance of the public streets.

Maintenance of an absolute contact of metal, which obviates the necessity of "bonding joints" in electrical traction.

First cost not greater than that of the Johnson, Wharton, or Lewis & Fowler systems.

H. W. Brinckerhoff, M. Am. Soc. C. E.—In the earlier editions of Trautwine's hand-book is a statement, of which I was reminded by something that was said in the duplex paper on the duplex rail, to which we have just listened. The paper speaks of the necessity of allowing for the expansion and contraction of the rails. The statement was to the effect that it is a remarkable fact, not satisfactorily explained, that when rails, even for a length of several miles, were firmly riveted or welded together, no expansion or contraction during variations of temperature was observed. Of course, it is easy to calculate that if the rail is laid at a mean temperature the tensile and compressive strains due to ordinary variations of temperature will not reach the elastic limit. I wrote, however, to Mr. Trautwine to ask the authority for the statement, and he replied that it was taken from the proceedings of the British Institution of Civil Engineers, and was found in a discussion in which Brunel and Stephenson took part. The fact was not questioned, and the discussion was only as to how it was to be explained. I think a similar case was mentioned in a paper recently read before this Society, where the rails were united by rivets, and the ties covered with turf, and no trouble was experienced from expansion or contraction.

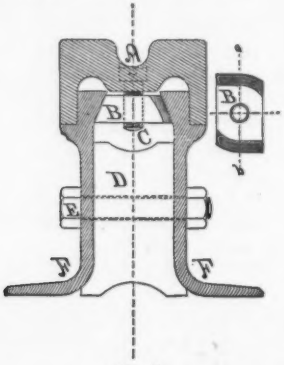


Fig. 26.

Perhaps it may not be remembered by all of us that when the Brooklyn Bridge was being built it was intended to have provided for horse-car tracks on the roadway, and several forms of track were devised for use on the approaches. Among them was one like that shown in Fig. 26: *A* is the rail proper, which has a central groove for the wheel

flanges, and may receive the tread of the wheel on either side. *F F* are supports of rolled iron or steel, which when bolted together, as at *E*, through a cast-iron separator, *D*, form a sort of continuous box-girder.

In laying this track, the substructure, *F F*, etc., is first bedded on a layer of concrete and filled with the same material nearly up to the underside of wedge *B*. Then the wedges *B B* are attached to the rail *A* by the screw-bolts *C C*, whose heads are recessed into the bottom of the groove in *A*, so as to be out of the way of the wheel flanges. The wedges are turned so that the line *a b*, shown on the small plan at one side, is parallel to the axis of the rail, in which position they readily enter the opening between the supports *F F*, but when the screw *C* is turned the square shoulders of the wedge come to a bearing on the inner and inclined surfaces of *F F*, and by turning the screw still further, not only is the rail *A* drawn firmly down to its place, but the pieces *F F* are tightly set out against the vertical flanges of the rail, uniting all three pieces very firmly together. In a well-paved street, gauge-rods are hardly needed, but if desired, the bolts, *E E*, could be extended across at intervals from rail to rail for that purpose.

Some of the advantages of this form of track are: the ability to readily renew the surface when worn, with but little loss for "scrap" and no disturbance of the pavement; the avoidance of fish-plates, and the excellent support for the rail joints, the structure being practically continuous; great vertical strength and lateral stability, together with good support for the adjacent paving.

No tramways were laid on the bridge, however, and so this construction was never used.

MENDES COHEN, Vice-President Am. Soc. C. E.—As it has been stated that rails may be laid continuously, without strains or serious inconvenience from expansion, I may state that on the Baltimore and Ohio Railroad, about thirty-five years ago, the Chief Engineer, the late Benjamin H. Latrobe, designed a three-part rail, consisting of two side pieces and a T-shaped cap included between them, and all riveted together, forming practically a continuous rail. The slots in the cap were cut out oblong, and there was space left between the ends of the caps, so that expansion was supposed to be provided for. The practical working, however, was by no means satisfactory. It was my duty at that time to be engaged upon the locomotives running upon the road, and from my point of view on the engine, I saw a great deal of the trouble. My first experience of difficulty with it was in ascending a grade of 40 feet to the mile with a passenger-train; we came to the siding which the passenger-train should take; but could not throw the switch, which was of the shifting-rail type, then generally used. I got down, and we tried to get the train out of the way, but we found that the rail had stretched to that degree that it lapped over into the casting at the end, and the switch could not be moved. On inquiry of the switchman how he

had allowed that condition to exist, he said: "I have cut off that rail every few days, and I cannot do anything with it; I cannot keep the switch open; when I have cut off the rail on the south side I have added on the other side." It was a fact that, on the 40-foot grade, the one rail had moved to the eastward, or down-hill, and the other to the westward, or up-hill. It was not acounted for at the time. The same rail was being laid at several other points on the road, and at every point where it was laid we had that difficulty. There was no cause satisfactorily assigned for this motion. That it existed, I had no doubt at that time. I left the road within a few months afterwards, and had no opportunity of investigating it, and as the difficulty with the rail was rather a source of annoyance I never heard of its being investigated. I might say, still further, that I have seen from the point of view of the locomotive, the rail actually lifted right up with the cross-ties, somewhat as a wave ahead of the engine, and have seen the broken-stone ballast crowded and heaped up between the ties, as a result of similar movement. There was no question at the time as to the cause of it; it was the unfavorable condition of the rail, so far as expansion and contraction were concerned, and it was found so serious that the use of the rail was given up. I may further say that, when first laid down, so noiseless was the passage of the wheels over it, I have heard it compared in effect to a leaden rail. Such was its condition when I left the service. Two years later I passed over the road and found that the silent track had become a very noisy one from the wear and loosening of the rivets, though they had all been closed hot. A sectional and perspective view of this rail is given by Perdonnet —"Traité Élémentaire des Chemins de Fer," 2d edition, Vol. I, page 492.

Mr. C. B. Fairchild.—I desire to cite a case in point, in regard to laying rails end to end without provision for expansion. A portion of the Georgetown and Tenalleytown Electric Road, built within a year and a half, was laid with T rails, with the ends of the rails absolutely close together. This was on a portion of the line, however, outside the city limits, and the superintendent recently informed me that after putting down the rails they drew the soil up to the rails on both sides, and that they have had no trouble whatever from the expansion and contraction His theory was that the ground kept the temperature of the rail nearly uniform, and it did not seem sufficiently heated to expand to any appreciable extent. Within the city limits, however, the rails were put down with provision for expansion.

Mr. Wm. Richardson.—I cannot say how it is in the vicinity of Washington; but I do know how it has been in this city; where sometimes the thermometer will run up to 90 in the summer and drop nearly to zero in the winter. Tracks were laid in Beach and North Moore streets in this city about the year 1865, and were not used for some time afterwards; and in the summer time, not having space allowed for the expansion of the rails, the string timber was lifted right out of the ground,

the rails getting loose from some of the timber. The result was that the tracks were all drawn out so much that they had to be relaid.

Take, as a sample of the extent of this expansion, the rails of the New York Central Railroad, between Albany and Buffalo; they will measure about a mile longer in a hot day in summer than in a cold day in winter. The result is that we have practically, in laying our street railways with rails 30 feet long, to allow ¼ inch between joints; and that is regularly done by trackmen who cannot perhaps tell you why they do it; but it has to be done, to keep the rails from springing up by reason of lengthening out in hot weather. I think that perhaps it could be obviated with a continuous rail, if we could have one that would not be expanded sufficiently to draw it up from its fastenings; if it was absolutely one rail; but that allowance should be made on rails of 25 and 30 feet in length for that expansion during the heated term, every practical man knows.

R. L. HARRIS, M. Am. Soc. C. E.—Any one who has had much track-laying to do will not need to discuss this matter of expansion to any extent. It is a curious fact, that upon the original Market Street Railway, in San Francisco, with T-rails, one rail would journey one way and the other the other; it seems partly due to some other reason than expansion and contraction.

Mr. BRINCKERHOFF.—What was the nature of the rail that crawled in San Francisco?

Mr. HARRIS.—A tee-rail.

Mr. BRINCKERHOFF.—That was probably the reason. We all know of the uneasy rails of the St. Louis Bridge, which keep a gang of men busy cutting them off on one end and carrying the pieces around and putting them on the other end.

In this case the trouble is said to be due to the fact that the rail, which is of the ordinary tee pattern, is laid on longitudinal stringers, and in the deflection caused by a passing load, the bottom of the rail is extended while the top of the stringer is compressed; and so the one continually crawls upon the other, causing this curious annoyance, the rails always moving in the same direction as the trains.

The CHAIR (WILLIAM P. SHINN, President Am. Soc. C. E.)—I wish to add a word or two on my own account. I have no doubt that the importance of elasticity in track has been exaggerated, that its value has been greatly overestimated. As has been concisely stated by one speaker, elasticity is important where you have irregularities; if you have a perfect track, you do not want an elastic track. I well remember as among one of the early lessons in railroading which I received in my young days, that the locomotive engineers were perfectly sure, and announced it as a result of observation and experience, that they could haul two more cars loaded with live stock than they could haul loaded with coal, because the live stock was elastic. I think in this

you have a demonstration of the character of this so-called elasticity. I hope that our members, and our railroad friends outside of the membership, will devote their attention to getting a perfectly smooth track and not so much to getting an elastic track.

Mr. F. Collingwood, M. Am. Soc. C. E.—For the sake of completeness, I present Fig. 27, showing another rail device for the New York approach of the East River Bridge, which explains itself. The chairs were to be kept in gauge by the bars connected to their bases. The chairs were to be at 5 feet intervals, and to weigh 90 pounds each. The I-beams to weigh 80 pounds per yard. The rails to weigh 55 pounds per yard, and to have a layer of tarred paper between them and the I-beams. The whole height to be 19 inches. A continuous plate, 9 x ½ inches, between the I-beam and the chair, serves for the lower attachment of the hook-headed bolts for securing the rails in place.

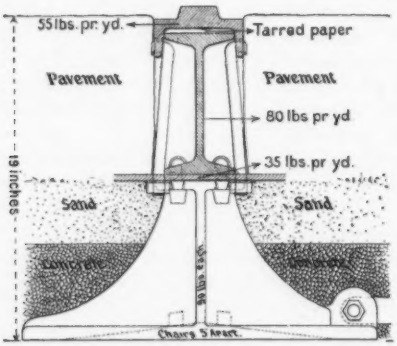


Fig. 27.

Mr. Gribble, in concluding the discussion, expressed his acknowledgments of the kind vote of thanks passed at the reading of his paper, and for all the criticisms upon it, and said, further: With regard to Mr. Tratman's remarks upon the gauge of street railways, it is evident from the figures recommended by the Report of the American Street Railway Association that their object was to enable foreign vehicles to use the rails. This appears to me a practice only defensible, on the ground of the inability of impecunious municipal corporations, to provide suitable roads or pavements for ordinary vehicular traffic, and unworthy of the present financial status of the larger American cities.

It has been a subject of enquiry amongst street-railway men as to why they should have to use heavier rails to carry lighter loads than on steam railways. A letter signed G. H. T. appeared in last month's

Street Railway Journal, showing the position, and appealing for an explanation. I will suggest three:

First.—Because the abrasion of rails on street railways is very much more than on steam railways, largely owing to bad pavements.

Second.—Because in order to obtain an elastic rail and to economize chairs, rails are placed upon double the distance between bearings in cities, of that on steam railways.

Third.—Because rails are designed without sufficient regard for their static stiffness. The same rail-makers exhibit patterns to do the same work, one of which will differ by fifty per cent. from the other in stiffness, and nearly as much in strength. The economic advantage of a continuous support has been already dwelt upon. The counter advantage of elasticity in the rail is not given to us in figures by those who advocate it for street railways, but it may be easily arrived at. Let us take for instance the 78-pound rail, Fig. 18, having no bottom flanges, placed upon bearings 5 feet apart, and regard it as safe under a working load of 20 000 pounds, such as that of an electric car. This rail only does the same duty on a street, that a 50-pound rail of the ordinary flanged tee-section will do upon a steam railway. The chairs are placed upon concrete blocks, and the rail is boxed up with sand ballast. There is, therefore, no elasticity of road-bed, such as is illustrated on Fig. 13. There is only a very slight elasticity in the rail itself, possibly $\frac{1}{35}$ of an inch deflection as against about 2 to 3 inches in the car springs. There is no special virtue about the $\frac{1}{35}$-inch spring of the rail to mitigate shock, more than the same amount of deflection in the car spring. It does not appear sound economy to increase the necessary weight of rail section 28 pounds per yard, in order to provide about one-hundredth part of the total elasticity. If Mr. Gibbon were to enlarge the foot of his rail so as to obtain something of a bulb form, he would, with the same amount of material, obtain a great increase both of strength and stiffness. This, he says, has been done. If, moreover, the chairs were placed 2 feet 6 inches apart, and the rail flanged as on steam railways, the deflection of the rail would be reduced to about $\frac{1}{3000}$ part of that of the car springs, and would be absolutely inappreciable. Seeing that all city streets are too hard to give any elasticity of road-bed, and the elasticity of a rail itself is so trifling, these two elements of elasticity may be abandoned. There is, however, a kind of elasticity produced by a support of timber, such as a cross-tie, which assists in mitigating the effect of shocks, more than one of metal or stone. Wood does not spring as much as iron or steel, but it is softer, and absorbs the percussive action like a cushion. What causes the percussive action will be presently enquired into, but it may be said here in advance that a wooden support, whilst mitigating shock at the outset, always ends by increasing it, because it does not spring under the repeated loads; it squeezes, and

apart from its decay, it creates a shock from the unevenness produced by wear, particularly at the joints.

The Wharton system, as carried out at Pittsburgh, consists in laying a grooved flangeless tee-rail having a light web, on chairs 2 feet 6 inches apart, placed on timber cross-ties. Even on so short a span as 2 feet 6 inches, there is percussion in the passing of a wheel over the support, and there would be a gain in using timber, as long as it lasted; but I contend for the principle of a continuous metallic support, as a means of removing the cause of shock itself, and I further claim that the unsatisfactory results with some such systems, when accounted for, confirm the truth of that principle. As several speakers have reiterated, the joint is the weak point of a rail, but it is so because the rail is relied upon, more or less, to furnish stiffness under deflection, as a girder. If, however, the stiffness is all furnished in the support, and if that support is so designed as to have a uniform strength throughout, with no weak point in it, the rail may have as many joints as we please, without affecting the deflection of the structure and without producing shock.

The Causation of Shock.

I will now attempt to sum up the question of elasticity, by enquiring as to the reasons of uneasy riding, otherwise the causation of shock, in street-car travel, about which there is considerable difference of opinion. We are all agreed as to the effects of suddenly applied loads upon rails, especially upon suspended joints. The fan-like bruise betrays the percussion, and the speedy loss of weight the force of abrasion, but we are not so clear as to the cause.

The *rigidity either of a road-bed or a rail* may increase the effect of a shock but it cannot produce it. It is important to distinguish between cause and effect in this particular.

Shocks upon railways arise from an unequal resistance to the passage of the load. If they arise from a weak suspended joint, it is an unequal resistance to deflection. If from the transition from an elastic rail to a rigid support, it is also an unequal resistance to deflection. If from roughness of the rail surface from grit or worn rails, it is an unequal resistance to rolling contact. If from flattened wheels, bent axles or similar defects of rolling stock, it is also an unequal resistance to rolling contact. If from a suddenly applied brake or a sharp curve, it is an unequal resistance to traction.

We do not put springs upon sleighs, although the surface they glide on is often perfectly hard. It is smooth, and offers a uniform and slight resistance to sliding contact. I have traveled at a speed said to be 100 miles an hour upon the "Chemin de fer glissant," the road-bed of which was entirely rigid. No one who has traveled on the "Flying Dutchman," the fastest train out of London, can fail to pronounce it the easiest traveling in that country, but it is upon a rigid track. If we were to put

down a way of polished steel upon a thickness of many yards of solid granite, we could ride upon it in a car without springs, perfectly smoothly; but if we were to place even a sheet of paper on the track, we should feel the passage.

All English tramways are rigid, but no one will contend that they all ride hard. Mr. Tratman complains of some of them, but he does not tell us what their condition was, whether they were clean, and whether they were well laid. All grooved rails are necessarily dirtier than step-rails, and it is surprising how little dirt upon a rail, especially when frozen, will make the most elastic track ride hard; a tight gauge or a rigid car spring will do the same.

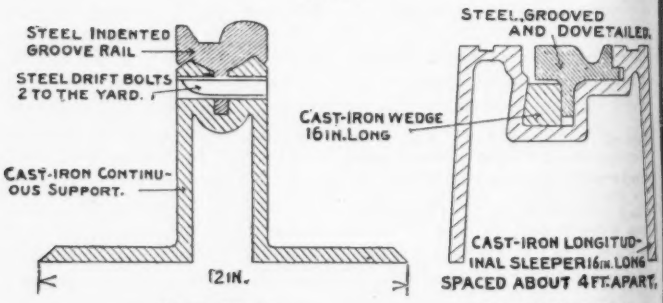
Fastenings.

Mr. Tratman is of opinion that my proposed rail would be better with more depth, with which to provide vertical stiffness, and with fewer fastenings. I will take up this point along with a criticism of Mr. Gibbon's Albany track. I have just stated my reasons, for aiming at obtaining all the required stiffness in the support rather than in the rail, but I go farther. I seek not only a continuous support, but a continuous fastening. There is a vertical movement in a weakly fastened rail, even upon a continuous support, as for instance, the ordinary flat rail spiked down to timber stringers. The rail begins to chatter long before it actually breaks its hold, and there must be an imperceptible vertical movement long before even the chattering begins. It is here that my object has been to get at the origin of the evil and obtain a fastening which will be practically continuous, and so constitute the rail a mechanical unity with its support. I further arrange the key-seats so that distance pieces can be placed between them to prevent any one wedge from starting without first starting the whole series; and as the taper of half the wedges is in the opposite direction to the other half, there is an absolute impossibility for any one wedge to start. In Mr. Gibbon's Albany track the keys are not wedges; they are thin plates of iron which pass through the sleeper and the web of the rail, but the resistance to vertical movement is only in the direction of the least dimension of the key. There is a leverage against the key, of half the width of the sleeper, and the web of the rail must act upon it like a man springing upon a spring-board. The sleepers are only semi-continuous, so that as the load passes from the unsupported portion of the rail to the sleeper it must produce percussion; and as the sleepers are not anchored, I should imagine that unless secured by the adjacent pavement, there would be some likelihood of displacement.

Mr. Gibbon terms his present system a development of the Albany track, but it appears to me a departure in principle from it and a virtual abandonment of his first ideas. The tendency of his remarks is to discourage us from attempting to employ a continuous metallic support on

account of its costliness, and from using concrete on account of its rigidity. I think that Mr. Gibbon's difficulties with the Albany track are instructive, but in a different way. The Albany track resembles in some respects the Cockburn-Muir track shown on Fig. 28. That has also a semi-continuous metallic support, but it has a longitudinal key which wedges up the web of the rail hard against the side of the sleeper. This wedge is as long as the sleeper, and has been very satisfactory. The rail, in addition to this, has a dovetail or lip which fits into a corresponding seat in the sleeper. This is a very superior fastening to the Albany track. In one respect Mr. Gibbon's track resembles the Barker rail shown on Fig. 28. There the support is continuous, and the fastening, like the Albany track, is transverse; but the rail is indented so as to preclude lateral movement, and the key resembles a drift-bolt, having a taper by which to draw down the rail to a firm bearing. This is also a very superior fastening to that of the Albany track. I have ridden in Manchester upon the Barker rail, and can speak well of it. The only improvement made upon it by the inventor has been to double the number of fastenings. Both the Cockburn-Muir and the Barker systems, have

FIG. 28.


STEEL INDENTED GROOVE RAIL
STEEL DRIFT BOLTS 2 TO THE YARD.
CAST-IRON CONTINUOUS SUPPORT.
12IN.
STEEL, GROOVED AND DOVETAILED.
CAST-IRON WEDGE 16IN. LONG
CAST-IRON LONGITUDINAL SLEEPER 16IN. LONG SPACED ABOUT 4FT. APART.

BARKER SYSTEM. COCKBURN-MUIR SYSTEM.

been proved successful on a large scale, and for many years. They both employ concrete, although they do not obtain from it any material anchorage, they only use it as a foundation. Both sections, like those of both Mr. Gibbon's tracks, lack the lower flange, and consequently do not obtain the greatest efficiency possible from the material. The Barker rail does not need stiffness, because it is continually supported. The web is of no use except for purposes of attachment.

The Albany track, like the Cockburn-Muir, is upon a semi-continuous support, and, therefore, requires vertical stiffness between the sleepers. When the former was tried with concrete filling in the sleepers, the verdict, stated with judicial brevity, appears to have been, "too rigid," and the inventor to have bowed to the verdict. I am disposed

to hazard the opinion that the reason was not that the supports were too rigid, but that the rail was too elastic between those supports—partly from its section and partly from its attachment—and so when passing from a yielding rail to a rigid support, the result was a jarring sensation.

Anchorage.

Coming to the subject of anchorage, Mr. Gibbon criticises my rail as having no absolute anchorage in the concrete; and as that is one of the points I have aimed at more than any other, and without which I should feel that I had made no improvement, I will illustrate the anchorage that I obtain by the application of my rail to cable roads. See Fig. 29.

Arrangements for Cable Roads.

4 feet 8½ inch gauge, with rolled slot-rail and granite paving.

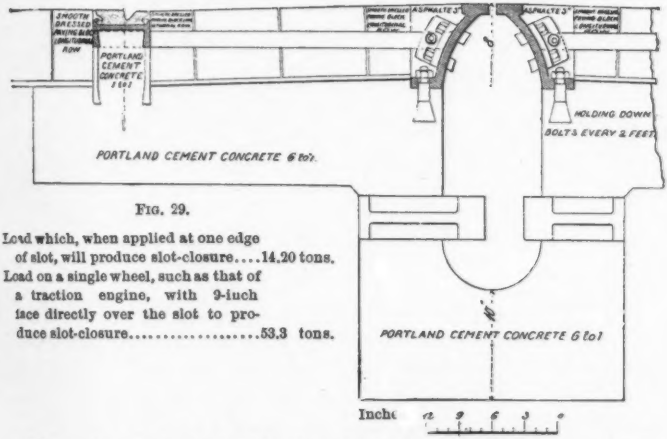

SMOOTH DRESSED PAVING BLOCK
CONCRETE ROW
PORTLAND CEMENT CONCRETE 1 to 1
ASPHALTE 3"
ASPHALTE 3"
HOLDING DOWN BOLTS EVERY 2 FEET
PORTLAND CEMENT CONCRETE 6 to 1
PORTLAND CEMENT CONCRETE 6 to 1
Inches 12 9 6 3 0

Fig. 29.

Load which, when applied at one edge of slot, will produce slot-closure....14.20 tons.
Load on a single wheel, such as that of a traction engine, with 9-inch face directly over the slot to produce slot-closure.....53.3 tons.

The anchorage is obtained by the cohesive strength of the cement and the tapered form of the metallic sides, combined with the transverse web. To withdraw one of these boxes from its foundation would require on a length of 12 feet about 100 tons, so that practically the box would carry away with it the whole foundation before parting company. It is a simple application of the familiar device of a "Lewis bolt" for lifting large blocks of masonry.

The result, as applied to maintaining a slot-rail from closure, is given numerically upon the illustration, and I see no reason why the entire yoke system should not be dispensed with under this method.

In conclusion, I regret that I am unable to reply to all the criticisms which have been made by Mr. Gibbon. I think that most of them, as

for instance the precaution adopted for protecting the lugs in the last figure, will explain themselves by a close inspection of my different illustrations.

I have explained the principles upon which I have been seeking to produce some improvements in street-railway track. Whether my ideas are correct or not will have to be proved by actual test, which I hope to make as soon as the weather permits.